Human Behaviour and Ecosystem Services in Sustainable Farming Landscapes

An Agent-Based Model of Socio-Ecological Systems

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Thesis Abstract

Agricultural areas represent around 40% of the earth surface and provide a variety of products and services essential to human societies. However, with policy reforms, market liberalisation and climate change issues, continuous land use and cover change (LUCC) brings uncertainty in the quantity and quality of ecosystem services supplied for the future generations. The processes of LUCC have been explored using top-down approaches at global and regional level but more recent methods have focused on agents' interactions at smaller scale. This approach is better suited to understanding and modelling complex socio-ecological systems, which emerge from individual actions, and therefore for developing tools which improve policy effectiveness. In recent years, there has also been increasing interest in gaining more detailed understanding of the impacts of LUCC on the range of ecosystem services associated with different landscapes and farming practices. The objectives of this thesis are: 1/ to understand and model the internal processes of LUCC at local scale, i.e. farmer behaviour, 2/ to explore heterogeneous farmer decision making and the impacts it has on LUCC and on ecosystem services and 3/ to inform policy makers for improving the effectiveness of land-related policies. This thesis presents an agent-based modelling framework which integrates psycho-social models of heterogeneous farmer decisions and an ecological model of skylark breeding population. The model is applied to the Lunan, a small Scottish arable catchment, and is empirically-grounded using social surveys, i.e. phone interviews and choice-based conjoint experiments. Based on ecological attitudes and farming goals, three main types of farmer agents were generated: profit-oriented, multifunctionalist, traditionalist. The proportion of farmer types found within the survey was used to scale-up respondent results to the agent population, spatially distributed within a GIS-based representation of the catchment. Under three socio-economic scenarios, based on the IPCC-SRES framework, the three types of farmers maximise an utility function, which is disaggregated into economic, environmental and social preferences, and apply the farm strategy (i.e. land uses, management style, agri-environmental measures) that best satisfies them. Each type of agents demonstrates different reactions to market and policy pressures though farmers seem to be constrained by lack of financial opportunities and are therefore unable to fully comply with environmental and social goals. At the landscape level, the impacts on ecosystem services, in particular the skylark local population, depend strongly on policy objectives, which can be antagonist and create trade-offs in the provision of different services, and on farmer socio-environmental values. A set of policy recommendations is offered that encompasses the heterogeneity of farmer decision-making with the aim of meeting sustainable targets. Finally, further improvements of the conceptual and methodological framework are discussed.

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This thesis is dedicated to all those who gave me the strength. And finally thank you Scotland for everything! Forever, wherever…

Eléonore Guillem

Own Work Declaration

I hereby declare that this thesis is my own composition, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or professional qualification except as specified.

E.E.Guillem

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List of Abbreviations

AAPS	Arable Area Payment Scheme
ABM	Agent-Based Model
AEM	Agri-Environmental Measure
AES	Agri-Environmental Scheme
ALARM	Assessing Large-scale Risks for biodiversity with tested Methods
BAMBU	Business-As-Might-Be-Usual
BEFM	Bio-Economic Farm Model
BTO	British Trust for Ornithology
CAP	Common Agricultural Policy
CBC	Choice-Based Conjoint
CHANS	Coupled Human And Natural System
DEFRA	Department for Environment, Food and Rural Affairs
DPSIR	Driving Forces-Pressures-State-Impacts-Responses
EEA	European Environment Agency
ER-AES	Ecologically Related- Agri-Environmental Scheme
ESU	European Size Unit
FAD	Farm Account Data
FAO	Food and Agriculture Organization
FMH	Farm Management Handbook
FSR	Farming System Research
GHG	GreenHouse Gas
GIS	Geographical Information System
GRAS	GRowth Applied Strategy
HCBC	Hierarchical bayes Choice-Based Conjoint
IACS	Integrated Administration and Control System
IBM	Individual-Based Model
IEEP	Institute for European Environmental Policy

IPCC	Intergovernmental Panel on Climate Change
JAC	June Agricultural Census
JNCC	Joint Nature Conservation Committee
KMO	Kaiser-Meyer-Olkim test
LP	Linear Programming
LUCC	Land Use and Cover Change
NVZ	Nitrate Vulnerable Zone
PCA	Principal Component Analysis
RERAD	Rural and Environment Research and Analysis Directorate
RSPB	Royal Society for the Protection of Birds
SAC	Scottish Agricultural College
SEDG	Sustainable European Development Goal
SES	Socio-Ecological System
SFP	Single Farm Payment
SRDP	Scotland Rural Development Programme
SRES	Special Report on Emissions Scenarios

Chapter 1

General Introduction

1. Research arguments and interests

1.1 Farming landscapes as socio-ecological systems

Agricultural areas represent about 36% of the terrestrial surface and more than 71% of the United Kingdom (FAO, 2009a). In the 1970s and 1980s, the intensification of management in these areas led to the degradation of ecosystems. The services provided by these ecosystems are crucial to local and global societies, e.g. food, air and water quality and amenity services. The direct and indirect effects of ecosystem services on the human and of the humans on the provision of services have motivated academics and policy makers to rethink the problem of ecosystem services provision and sustainability from a more comprehensive point of view. First, environmental and social issues are interrelated and co-evoloving (human-nature feedbacks), hence frameworks for socio-ecological systems (SES) or coupled human and natural systems (CHANS) are promoted for this analysis. In these frameworks, the processes underlying system dynamics are understood to be the interrelationships between resources, resource users and higher level authorities (Anderies et al., 2004; Haines-Young and Potschin, 2010). This necessitates the integration of several disciplines and a variety of data at different spatio-temporal scales, which constitute methodological and conceptual challenges (Stoorvogel, 1995; Vedkamp and Lambin, 2001; Millenium Ecosystem Assessment, 2003; Baker, 2006; van Meijl et al., 2006; Rammel et al., 2007; Dawson et al., 2010).

Agricultural policies are now oriented towards the sustainability of agricultural areas that aims to maximise the economic, environmental and social values of the system. However, constant pressures from global market, policies and climate lead to a perpetual realignment of this equilibrium. This is particularly visible through land use and cover change (LUCC), which simultaneously reorganises the structure and composition of the ecosystem that in turn alter the provision and quality of services provided (Ferrari, 2003; Ewert et al., 2005; Rounsevell et al., 2005).

To understand and anticipate LUCC it is important to see it as a function of external pressures and individual responses to these pressures (Gaskell and Winter, 1998; Lambin et al., 2000, 2001; Veldkamp and Lambin, 2001). Most researches have focused at global and regional scales (Alcamo et al., 1998; Metzger et al., 2005; Audsley et al., 2006), which are not appropriate for recognising the complexity of individual responses and interactions (Berger, 2001). At local scales however researchers can identify the internal processes underlying the state of the system and improve the transparency in modelling SES (Vedkamp and Lambin, 2001). For instance, diverse farm strategies can be observed in a catchment, even when the biophysical conditions and cultural milieu are similar (Edwards-Jones et al., 1998; Soman et al., 2008; De Chazal, 2010). From this observation, a number of studies have shown how farmers are not simply profit-maximisers but make choices through a complex process involving a variety of personal values (e.g. Gasson, 1973; Smith and Capstick, 1976; Shucksmith, 1993; Beedell and Rehman, 1999; Schoon and Grotenhuis, 2000). The study of farmer's decision making is therefore required to understand LUCC, and ultimately for policy design and effectiveness. In particular, it allows the researchers to identify barriers and drivers of behaviour (Shucksmith, 1993; Schoon and Grotenhuis, 2000), which arise from local cultural influences, demographics of the farm household, characteristics of the business, past experience, personal values etc. (Meert et al., 2005).

One of the conceptual challenges is to integrate these psycho-social models within models of LUCC (Rindfuss et al., 2008). Another requirement is to confront reality by implementing accurate representations of a system. This means that LUCC models should be empirically informed (Bakker and van Doorn, 2009; Rounsevell et al., 2012).

1.2 Sustainability, LUCC and Ecosystem services

Ecosystem services are of high value to society. This is demonstrated in the various ecosystem classifications available to date, e.g. the Millenium Ecosystem Asssessment (MEA, 2003), The UK National Ecosystem Assessment (UK NEA, 2011), the Common International Classification of Ecosystem Services (CICES, Haines-Young and Potschin, 2010). The UK NEA is a MEA-type assessment,that classifies ecosystem services into four broad categories of services, which underpin the delivery of a number of public goods: supporting services (e.g. nutrient cycling) on which the other groups of services depend, provisioning (deliver for instance food and energy), regulating (e.g. climate regulation, pollination, erosion and pest control) and cultural (e.g. recreation, cultural identity, heritage).

The services and goods arise from the interactions between physical and biological processes taking place in ecosystems. These processes depend strongly on biodiversity, i.e. variability among organisms (Chapin et al., 2000; Balvanera et al., 2006; Haines-Young and Potschin, 2010; Mace et al., 2011). Supporting services, for instance nutrient cycling, are improved by an optimal composition of micro-organisms present in the soil (Bradford et al., 2002). A biodiverse ecosystem also contributes to the provision of regulating services, e.g. resistance to pests (Altieri, 1999), resilience to environmental change (Chapin et al., 2000). However, the diversity in species depends on the diversity of habitats that are found in an ecosystem. LUCC has a direct impact on habitat quality and quantity, and therefore on ecosystem services provision. Agricultural LUCC is itself directly affected by external pressures and individual decisions (Lambin et al., 2001), making the farmer a determinant provider of ecosystem services. Indeed, as part of the numerous ecosystem services provided by farming activities, the production of food is probably the most important for human survival and, from a farmer point of view, often the main purpose of farming (Burton, 2004; Burton et al., 2008). However, the supply of a particular service can have negative impacts on the supply of others (Rodriguez et al., 2006; Polasky et al., 2011). For instance, while intensive management maximises the amount of food produced, it has deleterious effects on others, e.g. damage of traditional aspects of landscapes, water and air pollution, loss of recreational assets (Giampietro, 1997; Power, 2010).

Farmland birds are a good indication of the important effects of LUCC and agricultural system management, and they also provide many ecosystem services recognized by the MEA and UK NEA (e.g. pollination, pest control, see Whelan et al., 2008; Wenny et al., 2011), particularly cultural ones. In the UK, birds provide cultural services to the general public: bird watching, cultural identity, conservation actions (e.g. RSPB, SWT) and education (e.g. the Big School Birdwatch Initiative) (Church et al., 2011). Populations of birds are also good indicators of the quality of ecosystems, wildlife and countryside in general (UK Biodiversity indicator[1]) since they are near or at the top of the food chain (Furness and Greenwood, 1993). Their abundance and species richness may therefore indicate the presence of an adequate level of biodiversity, which determine the good functioning of ecosystem processes that underpin the provision of other services and goods. Birds in agricultural areas have however experienced a strong decline since the 1970s (Newton, 2004; Siriwardena et al., 1998). Intensification and simplification of the agricultural landscapes are among the main causes (Fuller et al., 1995; Wilson et al., 1997; Chamberlain and Fuller, 2000; Chamberlain et al., 2000; Robinson and Sutherland, 2002; Newton, 2004; McCracken et al., 2007). This resulted in loss of habitats due to an increase in the size of farms and fields, a decrease in the amount of non-productive areas and in the variety of crop types at farm and landscape levels, an accentuation of chemical input levels, an increase in the use of mechanisation, a decrease in fallow within rotations, a reduced consideration of stubbles, and a switch from spring to autumn sowing (McCracken et al., 2005; Henle et al., 2008).

The benefits of ecosystem services are non-excludable and non-rival to the public while private goods, such as farm holdings, are (Biltonen, 2011). For that reason, despite a fast evolving area of research, the valuation of ecosystem services has been mainly economic-focused (e.g. willingness-to-pay, benefit-cost analysis) and was anticipated from a profit-maximisation point of view (Constanza et al., 1997). The market value is indeed easier to understand and is thought to have more power in decision making (Kemkes et al., 2010). But, similarly to the Smith's water-diamond paradox[2], ecosystem services have high values in use, and so contribute significantly to human welfare, but for most of them, low value in trade. Hence, the goods and services supplied by the agroecosystem, itself managed by farmers, have a subjective

[1] http://jncc.defra.gov.uk/page-4235
[2] Adam Smith (1723-1790), Scottish social philosopher and political economist. The water-diamond paradox stipulates that diamond has little use for human welfare but high economic value as opposed to water, which is essential to human survival.

value, or utility, determined by those who want to use and participate in its supply. This does not exclude the fact that for some people the reasons are financial. Therefore, while many studies only focus on the impacts of LUCC on ecosystem services, the perceptions of ecosystem services held by LUCC actors should be embedded within individual decision making since decision makers are both suppliers and beneficiaries (de Chazal et al., 2008; Rounsevell et al., 2009; Haines-Young and Potschin, 2010). The conceptual and empirical representation of ecosystem services as subjective values and how different these values or preferences are among a population of decision-makers are complex to characterize, and rare in the literature, especially when a coherent association of disciplines is required.

Besides, the rising concerns for climate change mitigation and adaptation makes the vision of sustainability even more complex. Bioenergy cropping is a new technology in farming, which allows new financial opportunities and may hinder GHG emissions (Demirbas, 2009). As an innovative cropping system, some farmers might be reluctant to apply the technology, which presents uncertainty in yield performance and prices (Sherrington and Moran, 2010), and on socio-environmental impacts, while others might adopt. The uptake depends on a farmer goals, attitudes and knowledge on the positive and negative consequences from application and on the schemes proposed.

Even with suitable information about environmental and social issues of farming, the process of decision making become very complex if researchers go beyond the profit-maximisation approach. In both policy making and farmers decisions, some compromises or trade-offs have to be met between ecosystem services provided (Rounsevell et al., 2010) and between sustainability principles (Zander and Kachele, 1999).

1.3 Agricultural policies

There have been many modifications to European agricultural policies since its initial application in 1962 after the Treaty of Rome (1957), possibly leading to LUCC and impacts on the sustainability of farming areas (Scottish Government, 2012). Initially, the Common Agricultural Policy (CAP) sought to increase productivity, stabilise markets and ensure the EU food supply through market regulation. By the 1980s, excess stocking, environmental degradation and rapid public expenditure increase created some issues. In a context where production was encouraged, farmers intensified their management and used economies of scale strategies, unwittingly participating in the loss of traditional features of farming landscapes (e.g. hedgerows, stone walls) and of habitats for wildlife (Henle et al., 2008). To overcome excess stocking, regulatory and voluntary set-aside schemes were implemented in the early 1990s (the so called MacSharry reforms). Subsequently, the Agenda 2000 reform provoked a shift in the EU budget expenditure from market support subsidies to coupled direct payments and rural development. The uptake of agri-environmental schemes started to show a progressive "healing" of the environment (Boatman et al., 2008). Nevertheless, land of good quality became more and more productive to adapt to production-based subsidies. In 2003, "decoupling" subsidies from production were granted under fulfilment of cross-compliance standards. This allows for the release of funds for environmental quality and encourages multifunctionality of farming systems. However, the decoupling of payments has created environmental-related issues such as the decline of livestock farming, which is expected to continue in the future (Neumann et al., 2011). In addition the relaxation, then recent abolition, of the set-aside regulation has led to a loss of ecological benefits (Gillings et al., 2010).

The policy instruments constitute very powerful stimuli to LUCC and tools for initiating farmers' behavioural changes (Lambin et al., 2001). In a report by DEFRA (2008), the need for successful policy interventions was typified by: Encouraging through subsidies and regulations signals; Enabling with appropriate tools; Exemplifying with measures and the benefits they bring to the system and community; and Engaging by inducing a change in attitudes and motivations. The latter objectives requires the comprehension of internal values of decision making and the definition of target people or groups of people, in particular the methods by which engaging successfully these specific targets (Berger and Bolte, 2004; Dreschsler et al., 2007; Cooke et al., 2009). This is even more important for *ex-ante* assessment of the newly proposed reform of the CAP post-2013. For instance, the shift of funds for direct payments to the agri-environmental schemes could have different consequences for different land managers (Scottish Government, 2012).

One example of the direct link between farmers' perceptions and behaviour is observed through the adoption of agri-environmental schemes (AES). The uptake of AES with regards to landholders' attitudes and goals has been of growing interest in the past two decades, e.g. Morris and Potter, 1995; Battershill and Gilg, 1997; Morris et al., 2002; Vanslembrouck et al., 2002; Fish et al., 2003; Jacobson et al., 2003; Herzon and Mikk, 2007; Ahnstrom et al., 2009; Greiner et al., 2009. The participation is usually reinforced by financial objectives (Morris and Potter, 1995; Wilson, 1997; Burgess et al., 2000), although Wilson and Hart (2000) have shown the importance of environmental and social objectives in decisions.
The adoption of AES is limited by investment costs (Wandel and Smithers, 2000), compliance cost and time of contract (Wilson, 1997; Ruto and Garrod, 2009; Christensen et al., 2011), risk attitudes (Stonehouse, 1996; Uri, 1998; Herzon and Mikk, 2007), lack of information (Wynn et al., 2001) and disinterest for environmental and social issues (Fish et al., 2003). Two types of AES are available in the UK: competitive and targeted (Higher Level, Land Management Contract), and non-competitive with broad objectives (Lower Level, Land Management Options). The latter is easier to take up but engender modest payment, which might prevent big farms, and very small ones, to enter. In addition this group of schemes do require high administration cost that might limit the support given to farmers complying with the measures, and therefore limit its effectiveness. The reasons underlying the process of decision whether to participate or not, and what kind of schemes is selected, are very relevant to increase effectiveness of agri-environmental measures (AEMs) by understanding how these measures fit within particular goals and attitudes. Indeed, there has been an unsatisfactory success of AES to reverse agro-

biodiversity loss and other environmentally-related issues, which was associated with the scale of applications of the diverse measures (Cao et al. 2009; Parish et al. 2009). Scheme options are often targeted at the field level when in fact the positive environmental and social impacts emerge from landscape level performance. Hence, the consideration of a multitude of decision makers and their interactions is extremely important to monitor sustainability and ecosystem services.

1.4 The situation in intensive arable areas of Scotland

Scotland has a vast agricultural area covering 80% of its total hectares (6.12 millions ha) but climate, poor soil quality and mountainous terrains limit its land use. The agricultural sector accounts for 1.3% of the Gross Added Value in 2004, 0.8% in 2010, and supports 3% of employment (Scottish Government, 2006, 2010). There is a symbolic importance of agricultural activities in Scotland despite a declining economic impact.

The decoupling of the direct payments has led to further abandonment of the high nature value uplands and the intensification of the fertile areas, with a switch from grassland to crops (SAC, 2008; Holland et al., 2011). In recent years, many studies have been carried out that demonstrated the depletion of ecosystem services in intensive arable areas, e.g. water-related issues (Vinten et al., 2010), soil erosion regulation (Wade, 1998), decline in farmland birds (e.g. Perkins et al., 2008).

A catchment, the Lunan, within these areas of Scotland was selected for the study. Farmers in this catchment are confronted with a number of socio-environmental issues; among these are air and water quality problems, the latter being the most (and only) problem being studied in this area (Vinten et al., 2009). A primary observation of past changes in land uses and other farming factors in this area permitted to indicate other potential socio-environmental issues. This was done through analysis of the catchment-related census data for the period 1995-2008 (Appendix A). A reduction in the area of cropland and grassland clearly appeared after 2003 (after the start of decoupled payment), with larger fields being cultivated. Increased field size implies a loss of land use diversity and of linear features, which reduce the availability of habitats for wildlife (Benton et al., 2003; Boatman et al., 2007). Winter sown cereals are progressively replacing spring cropping and vegetable crops are increasingly planted. Winter cropping result in the loss of stubble feeding grounds that are crucial to maintain bird populations over winter (Gillings et al., 2005) and reduce the suitability of nest sites for ground-nesting species (e.g. skylarks, In addition, there is a rise in other activities such as the production of bulb and flowers. The area of rough grazing, which presents high value for wildlife (Bignal and McCracken, 1996), is also decreasing. The average income is diminishing simultaneously with the number of regular staff on the farm, creating local social issues

Efforts have been made to encourage the farmers to halt the degradation of ecosystems in these areas, e.g. NVZ regulations, cross-compliance and agri-environmental schemes. However, EU expenditure towards direct payments and rural development is the smallest in Scotland among the EU-15 countries. Direct payments to Scottish farmers are based on the average subsidies distributed over the period 2000 to 2002, as opposed to a flat rate for English farmers. The historical model leads to more disparity in farming income since the model profits intensive large scale farms over smaller and pluriactive ones (AgroSynergie, 2011). In this case, conflicts may arise since the same cross-compliance standards must be met by farmers receiving uneven payments (Halmai and Elekes, 2006). In Scotland today, 33% of the total agricultural areas is maintained under cross-compliance regulations and only 10% is under competitive agri-environmental management, although the highest proportion of agricultural areas covered by non-competitive schemes over the UK (32% in 2006) (Scottish Government, 2009a). Since 2007, Scotland is the first EU member to have adopted a rural development plan based on regional priorities for competitive schemes.

2. Research approach

Improvement of past research approaches are needed to answer sustainability issues emerging from dynamic and complex SES in intensive arable areas (Edwards-Jones, 2006; Cooke et al., 2009). This necessitates on one hand the integration of different disciplines, methods and theories to solve a common problem and on the other hand to reflect the heterogeneity of actors decisions facing external pressures (Roling and Wagemakers, 2000; David et al., 2004; Angelstam et al. 2006).
A better understanding of complex multi-dimensional (social, economic, ecological) systems and of the interrelations that exist between different units of analysis is necessary prior to modelling and simulating LUCC (Perez-Vasquez and Ruiz-Rosado, 2005). In addition, simulations are particularly pertinent to prepare for uncertainty in future contexts. This has a strong value for policy making since researchers can test the reactions of farmers to diverse socio-economic, political and climatic situations (Sutherland, 2006; Sutherland et al., 2008).

Modelling LUCC and farmer decision making was commonly performed with static and reductionist approaches, where the effects of macro-level policy and of the emergence of individual actions were not considered (Davidson, 1987; Lev and Campbell, 1987; van Eijk, 2000: p.324). These lacunas might have played a role in the limitation of information diffusion, notably on environmental impacts, to a larger public and to policy makers. Interdisciplinary teams have developed in the 1990s to work within a systems approach (Grant et al., 1997), such as Farming System Research (FSR), in which a variety of farming goals and socio-economic constraints were included in models of farmers planning and assessment (Gilbert et al., 1980). FSR was qualified as “hard” system research and assumed objective rather than subjective system definition and boundaries (Grant and Thompson, 1997). Following Van Eijk proposal (2000), the farm system should be observed through its own perspective (“soft” system, Churchman, 1971) rather than from the outside to identify all the disciplinary characteristics that are relevant to its existence and form subjective boundaries (see also van Ittersum et al., 1998; Roling and Wagemakers, 2000). Therefore the farmer himself becomes the focal point in the system modelled.

Farmers' decisions directly imply land use types and their spatial allocation drawing a bigger picture to the landscape mosaic and its ecological impacts (e.g. number and variety of wildlife habitats). In 1994, Pretty and Chambers claimed that "personal behaviour and attitudes remain the great blind spot of agricultural research and extension". Roling and Wagemakers (2000) have first "made the flip" by considering "human reasons for", based on cognition and learning, rather than "causes to", e.g. the DPSIR framework (EEA, 1999).

Methods for modelling decision making have been developed by social scientists, psychologists and economists (Figure 1.1) to use mathematical algorithms that simulate choices. To make choices implies the existence of alternatives that humans compare using mental models and these "represent a distinct hypothetical modification that initiates a change in the system" (Grant and Thompson, 1997), e.g. rational choice theory, Simon, 1955, 1956. There are two main areas for modelling decision making, optimisation and socio-psychological models, which differ in the theoretical basis and model inputs. The first area computes numerical values and gives a solution that responds to an objective (i.e. optimizing) under a set of constraints. The socio-psychological models are based on qualitative or emotional values to explain a given behaviour, which is not necessarily an optimizing exercise. However, an optimisation approach can be rooted in a socio-psychological model (e.g. the particule swarm optimisation, Kennedy and Eberhart, 1995).

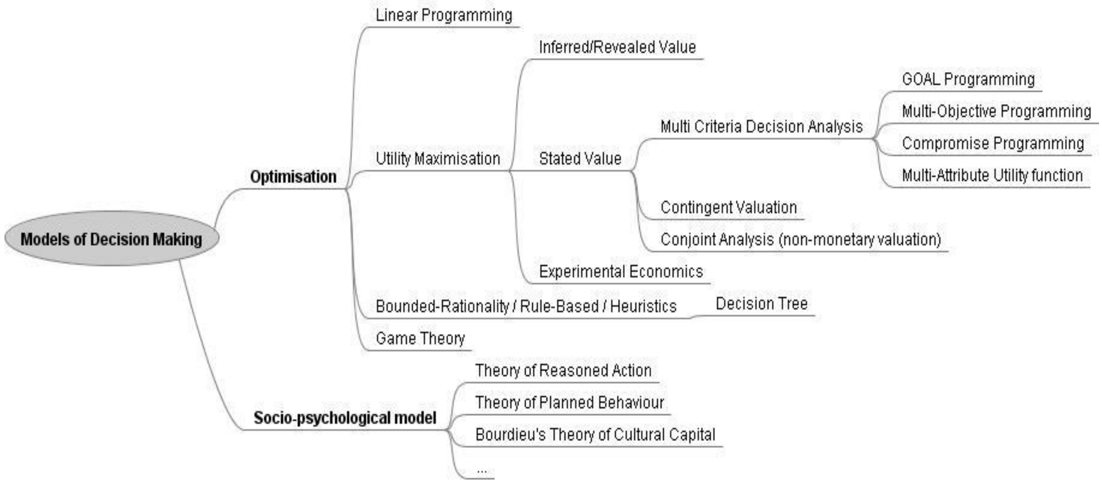

Figure 1.1 - Classification of decision making models

Linear programming (LP) has been widely used in farm management plan (e.g. Miller and Plantenga, 1999; Gibbons and Ramsden, 2008). This technique offers optimal land use planning from a small set of data, and can be tested under different socio-economic and biophysical scenarios, i.e. in Bio-Economic Farm Models (BEFMs, see review by Janssen and van Ittersum, 2007). LP has been combined with GIS in land use planning to permit the disagragation of LP solutions into spatially explicit land use (Chuvieco, 1993; Stoorvogel, 1995). However, the assumptions underlying the methods are restrictive since they stipulate that all functions are linear and the system is deterministic. For instance, uncertainty is not taken into account and the model solver gives a single optimal solution (Jeffrey et al., 1992), that maximise profit or minimise cost. The method is adequate when researchers are looking at problems that are assumed to be independent from the complexity of the system.

BEFMs have been improved to incorporate multiple goals into the utility maximisation algorithm, but they do not consider the heterogeneity of these objectives in a population of farmers living within the same locality, region or country, and how they react differently to external factors such as cultural and policies pressures, which limit the usefulness of the method for policy assessment (Janssen and van Ittersum, 2007). The existence of multiple criteria and objectives is particularly important in decision making when one has to make a compromise to arrive to a choice. The theory of utility has brought some insight into this process, upgrading the simulation of decision making to a more realistic level (Ghazali Mahayidin, 1982**;** Dyer et al., 1992). For instance, with conjoint analysis techniques, the subjective values of alternative choices can be derived and incorporated within utility functions (Adamowicz et al., 1997; Kurttila and Pukkala, 2003). This is very useful when one wants to represent a farmer choosing a certain land use not only to increase profit, but also because he/she has knowledge of its consequences on ecosystems and society. However, a decision maker has not the capacity to make ideal choices because his/her knowledge is limited (Swait and Adamowicz, 2001). The notion of bounded rationality has been included later in modelling techniques, i.e. in heuristics and game theory (Boone et al., 2006; Breton et al., 2006). Cabrera et al. (2010) have compared an optimisation method using LP with a heuristic method using decision trees. The rational agents tend to grow always the most profitable crops leading to a homogeneous landscape, while the heuristic agents do not show an "extreme" shift in land use change, making it more realistic.

The socio-psychological models describe farmers' behaviour as a combination of personality, lifestyle, and objectives (Wallace and Moss, 2002) and takes account of social norms and ability. Past experiences, farm size, family tradition or observation of neighbouring farming system are also influences on the decision of performing an action or not (Anderson et al., 1977; Vanslembrouck et al., 2002; Axelrod and Tesfatsion, 2005; Edwards-Jones, 2006).

All the methods and approaches reviewed above lack some of the fundamental elements characterising SES (Gilbert and Terna, 2000; Bonabeau, 2002; Macal and North, 2005; Rindfuss et al., 2008):

- Dynamic context
- Integration and coupling of sub-models
- (Non-linear) Human behaviour and decision making

- Emergence from a diversity of autonomous actors decisions and self-organisation of the system
- Spatial link with actors and their behaviour

Computational advances have permitted to develop methods to model LUCC and the effects on ecosystems services from a SES approach. The Agent-Based (or Individual-Based) Modelling (ABM, IBM) technique is particularly promising in this context (Matthews et al., 2007). The technique allows researchers to link social and ecological functions and to model decision making processes and adaptive behaviour at both the individual and system level (Parker et al., 2003; Janssen, 2005; Murray-Rust et al., 2011), and within higher spatial resolutions (van der Veen and Otter, 2001). The individual level is represented by “agents” who interact autonomously and heterogeneously with their environment and other actors through behavioural rules (Macal and North, 2005). The level of complexity and sophistication of behavioural rules depends on the research objectives, data availability and prior knowledge about the system (and the agents) to be modelled. From the behaviour of individual agents (e.g. farmers), ABMs allow the investigation of higher level, emergent patterns (e.g. LUCC) that arise from self-organisation of the system studied (Janssen, 2005). Applications of ABMs of LUCC have included the impact of innovations and policy on agricultural practices (Balmann, 1997; Janssen et al., 2000; Deffuant et al., 2000; Berger, 2001; Brady et al., 2009), reforestation and deforestation (Hoffman et al., 2003) and urban sprawl (Fontaine and Rounsevell, 2009). In parallel, a large number of ecological, Individual Based Models (IBMs) were developed from the late 1990s to simulate species population from the behaviour and life cycles of the individuals under different LUCC scenarios (Grimm and Railsback, 2005, p.122 for a review; see also relevant examples by Topping et al., 2005; Elderd and Nott, 2008).

The agent-based approach has been widely used recently in land-related studies but the next challenges are to make the decision making process of actors more transparent, to build on empirical evidence (Berger and Schreinemachers, 2006; Aalders, 2008; Rounsevell et al., 2012), and to explicitly represent the interactions between heterogeneity in actor decisions and ecosystem services outcomes (Luus et al., 2011; Milner-Gulland, 2012). The methods of data collection for empirical evidence should be relevant to characterise agents and their decision making process heterogeneously, e.g. social surveys, census database, experiments, participatory approaches (see review by Robinson et al., 2007; An, 2011), going beyond simple aggregate information. These data should be linked to spatial units or together within social networks to address adaptive behaviour in relation with change in policy, market, historical events, and stochastic processes. In addition, ABMs that represent human behaviour can be coupled with IBMs and other sub-models that simulate biophysical and ecological processes (Xu et al., 2009; Guillem et al., 2009; Murray-Rust et al., 2011).

3. Research objectives and outline of the thesis

The above literature review has highlighted gaps in current land use research and in the design of land-related policies. Accordingly, this thesis has the following objectives, namely to present the following:

1. Understand how farmers decision making contributes to the processes of LUCC and land management in intensive arable areas,
2. Analyse how heterogeneity in farmers decision making affects the spatio-temporal patterns of LUCC under various socio-economic contexts using an Agent-Based Model,
3. Explore how the provision of ecosystem services is affected by heterogeneous farmer reactions to external factors, and
4. Inform improvements in the effectiveness of land-related policies that support the sustainable management of arable farming areas.

The agent-based modelling approach used in this thesis is based on theoretical frameworks from the fields of social sciences, economics, biophysics and landscape ecology. The model is designed to explore the dynamic behaviour of heterogeneous farmers within an arable catchment, the various reactions to socio-economic and policy situations, and the sustainable impacts they generate. This necessitates an adequate prior knowledge on the different aspects of decision making, the elaboration of a conceptual framework, and the collection of data from various disciplinary fields. Psycho-sociological models of farmer decision making are combined with the non-monetary evaluation of ecosystem services and sustainability principles to make human behaviour more transparent. The model is also coupled with an individual-based model of skylarks, *Alauda arvensis*, for which parameters are estimated from data collected within the case study, in order to assess the effects of multi-agent interactions on ecosystem services. The ecosystem services considered in this thesis are provisioning (i.e. food and energy) and cultural (number of skylark) services. The farmers are considered as both providers and beneficiaries of these services. Although the general public is another major beneficiary, this entity is not considered in this research, i.e. the demand for services is not addressed. Following Lempert (2002), the model is not fully predictive but provides a basis for illustrating and discussing possible future challenges faced by intensive arable areas in conditions of "deep uncertainty".

This thesis is composed of six chapters including the general introduction, synthesis and appendices. Inputs to the model are available on the CD-ROM. The plan and trajectory of the thesis are represented in Figure 1.2. Chapters 2, 3, 4 and 5 are written after a series of journal articles, either currently in the review process, or accepted for publication (i.e. Chapters 2 and 3).

Each chapter has an underlying purpose related to the research objectives, and provides a trajectory for the thesis. The thesis is constructed from a theoretical basis to understand the general aspects of farmer decision making (Chapter 2), which is then refined to inform policy makers, and to empirically inform the agent-based model developed in the thesis (Chapter 3). Chapter 2 is a preliminary analytical research on the attitudes and goals of farmers in the case study area. In particular, it assesses and discusses the attitudes of farmers for the social and ecological aspect of farming, with special emphasis on birds, and improves our understanding of these aspects within decision making processes. In Chapter 3, a typology of farmers is generated based on attitudes and objectives, which serves as the characterisation of agents in the model and contributes to policy making by depicting the specific needs and wants of the different types. In addition, to refine and validate the typology, past behaviour is compared with regards to the farmer types using data from census surveys within the period 1995-2007.

The information generated in Chapters 2 and 3 is applied to an agent-based model, first to understand the dynamic mechanisms of farmer decision making from a bottom-up approach (Chapter 4), and finally to report the impacts of these processes on the sustainability and the provision of ecosystem services in the Scottish arable catchment (Chapter 5). In chapter 4, the agent-based model of farmer decision making and LUCC is described and analysed for three socio-economic scenarios. Particular attention is given to the utility obtained by farmer types in different scenarios and how they value their choices in terms of environmental, social and financial indicators. The results are integrated within the bigger picture of agricultural policies and are discussed to demonstrate the relevance of complex farmer decision making in models of LUCC. Chapter 5 includes the integration of the individual-based model of breeding skylark population within the ABM of farmer decision making. The results of these simulations highlight the aggregate effects of multiple farmer decisions under external pressures on the delivery of ecosystem services such as skylark local population, food and bioenergy production.

Finally, the main findings of the thesis are synthesised in Chapter 6 to respond to the thesis objectives. This section also considers the contribution of the thesis to land use research and policy, and highlights the needs for further research.

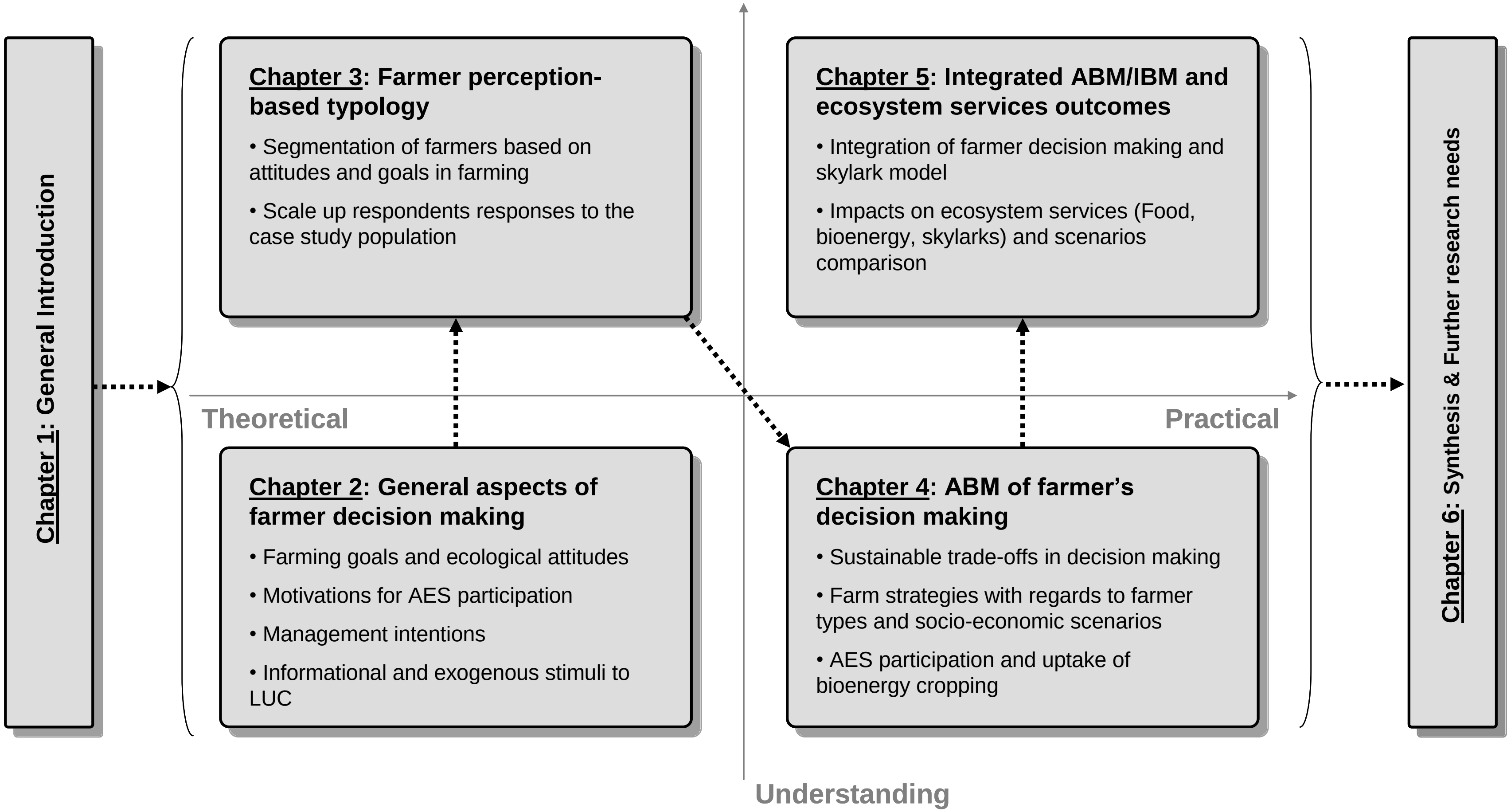

Figure 1.2 - Schematic interpretation of the thesis trajectory

Chapter 2

General aspects of farmer's decision making

Adapted from Guillem, E.E., Barnes, A. 2012. *Farmers' perceptions of bird conservation and farming management at a catchment level.* Land Use Policy, In Press.

Abstract

The future of the Common Agricultural Policy (CAP) in Europe suggests support for a "greening" of production related payments, however, the loss of set-aside and the increasing freedom to respond to market prices raises doubts on the actual consequences for farm-related ecology. Voluntary Agri-Environmental Schemes (AES) are believed to play a key role in the conservation of ecological attributes of farming landscapes. Nevertheless, the options proposed within these schemes are directed beyond a single objective and the level of participation remains low. This paper presents a fine-grained approach for examining the behavioural intentions of farmers within a catchment with regards to the moral consideration of specific ecological aspects of farming, such as the preservation of birdlife. The findings indicate that most farmers hold strong values towards birds living on their land and have incorporated this within their decision-making. Nevertheless, very few respondents intend to participate in these schemes in the future and this is due to some misinterpretations of the underlying ecological requirements for providing suitable habitats and bird population trends. In addition, the stated need by farmers for more measures focused on bird conservation implies a requirement for increasingly directed financial rewards and for proposing guidance that fits within current farm management.

Keywords: Farmer attitudes; Agri-environmental scheme; Attitudes to birdlife; Ecologically-friendly farming; Catchment; Farmer behaviour.

1. Introduction

Due to concerns for the consequences of intensive land use, agricultural policy has progressively shifted to wider social goals, principally towards the maintenance of environmental and ecological benefits. Agricultural intensification has led to wildlife habitat degradation and the loss of biodiversity, in birds (Fuller et al., 1995; Donald et al., 2001; Vickery et al., 2004; Newton, 2004); invertebrates (Benton et al., 2002); and plants (Sutcliffe and Kay, 2000). For instance, the UK's farmland bird indicator has shown a decrease of 48% of specialist species over the 1970-2007 period (RSPB, BTO, DEFRA, JNCC, 2009).

The most recent restructuring of the CAP, proposed for 2013, suggests support for a 'greening' of production related payments and increased funds for agri-environmental schemes (AES) (European Commission, 2009; Baldock, 2011), however, at present this is vaguely stated. Moreover, recent examples, such as the response to rising global cereal prices and the abolishment of set-aside, may be evidence that food production persists to be the main priority of EU farmers and agricultural policy. This raises doubts on how much "greener" the agricultural landscapes will be since, for instance, the significant "accidental" ecological benefits brought by the establishment of set-aside (Watson and Rae, 1997; Gillings et al., 2010; Tscharntke et al., 2011) have tended to diminish (Hart and Baldock, 2011). Increasing the level of participation within and the effectiveness of voluntary AES is certainly one answer.

Farmers operate under multiple policy goals and ambitions. They have to produce more food, adapt to climate change, whilst meanwhile protecting and improving the environment in which they farm (Tilman et al., 2002; Robertson and Swinton, 2005). The farmers can respond to these initiatives in a number of ways and it has become increasingly recognised that farmers, as individuals, attempt to balance a number of external and internal influences to make decisions about future farming practices (Shucksmith, 1993; Willock et al., 1999a, b; Sutherland et al., 2011).

The environmental perceptions of farmers can play a significant part in the process of decision-making. However, the broad environmental perspective is conceptually complex since it is intrinsically linked to financial (e.g. soil erosion impacts on yield), ecological (e.g. wildlife habitats) and social aspects (e.g. aesthetic value of the landscape) (see Wilson and Hart, 2000). A number of studies have shown the importance of environmental attitudes in farmer decision-making (e.g. Wilson and Hart, 2000; Fairweather et al., 2009) and in AES participation (e.g. Morris and Potter, 1995; Wilson, 1996, 1997; Wilson and Hart, 2000; Morris et al., 2002), but few have been focused on the ecological perspective, or oriented towards a specific ecosystem service deliverable (such as the supply of cultural services from biodiversity).

Ecological perceptions call attention to the “moral considerations” or the appreciation of the environment (Sullivan et al., 1996; Kaiser et al., 1999) in contrast to the environmental viability for production or utilitarianism. The failure to distinguish these two aspects, moral and utilitarian, can have important effects on both the conclusions drawn from the analysis of social surveys and the recommendations made to policy-makers.

There are numerous ecological functions that operate within the farm boundary. However, these are specific to an individual farm and the farmer will respond to this range of ecological indicators in a range of ways. A key function, identified by the UK NEA (Church et al., 2011), is the cultural value emerging from the supply of biodiversity, a prominent indicator of which is the number of headline bird species (Chamberlain et al., 2009; Davey et al., 2010; Baker et al., 2012). Policy makers, as well as farm ecologists use bird species as a headline indicator and it is reasonable to expect that farmers respond to high-level messages regarding the ecological health of farming through these indicators. Farmland birds also act as a biological crop control mechanism and can be perceived as a cultural component of the landscape (Jacobson et al., 2003), though by some as a pest and constraint on yield and land use potential (Coleman and Spurr, 2001). Accordingly, farmland birds represent the cultural and landscape values that are important to farmers within a community, which play a role in the motivations for maintaining and improving their habitats contained in the landscape (McHenry, 1998; Fish et al., 2003).

The study of farmer decision-making has become a powerful tool for policy development, in particular for the conservation of agro-biodiversity. There are several theories to describe this process, for instance that of the decision system (see Farmar-Bowers and Lane, 2009), Bourdieu’s notion of social capital (see Burton et al., 2008; Burton and Paragahawewa, 2011) and the theory of reasoned action (Fishbein and Ajzen, 1975), or later the theory of planned behaviour (Ajzen, 1985). This latter theory, in particular, assumes that behavioural intentions are related to the attitudes explicit of that behaviour (i.e. positive ecological attitudes related to ecological actions), and not by general attitudes (i.e. environmental attitudes).

Consequently, the aim of this paper is to examine the attitudes and values of farmer decision-making, with respect to the ecological aspects of farming, in particular the creation and maintenance of bird habitats. This expands current knowledge on the behaviour of farmers and offer possible opportunities for future development of ecological-based policies. The study is applied to a small, intensively managed lowland catchment of arable farmers within Scotland, which presents a mixture of farmer objectives and a landscape developed under both market and policy signals. The catchment level approach permits the understanding of the differences in perceptions with a more subtle degree of resolution. Nevertheless, we emphasise the implications for the wider farming community and policy makers in the discussion section. As such the paper is structured as follows, firstly an outline of agricultural policies and of the catchment itself, and then discussion of the instruments used to elicit understanding of decision-making. A results section details the findings of this study. Finally discussion and conclusion sections examine the implications of this study for the design of ecologically-related policies.

2. The environmental aspect in agricultural policies

The Fischler reforms of the Common Agricultural Policy (CAP), in 2004, have led to a softening of output related targets by supporting decoupling of payments from production. In addition, voluntary Agri-Environmental Schemes (AES), offered under Axis 2 support schemes of the CAP, are designed for actions that aim at protecting environmental resources. Although AES have been found to benefit biodiversity in most cases (Hanley et al., 1999; Peach et al., 2001; O’Brien et al., 2006; Perkins et al., 2008, 2011), their initial objectives were unclear and the uptake rate in the UK and particularly in Scotland has remained low (RSPB, 2007; Scottish Environment Link, 2009).

The Scottish Rural Development Program (SRDP) for the period 2007-2013 has been developed to include the three main principles of sustainability (economic, environmental and social) and to be output-focused (DTZ, 2007). It is composed of competitive and non-competitive elements. Cook (2009) has argued that the Land

Management Options under the Rural Development Contract, which are non-competitive, are insufficiently narrowed to achieve the desired outputs. The options proposed within these schemes are directed beyond a single objective. However, biodiversity targets and the protection of some charismatic species can only be achieved through the implementation of specific measures (Tscharntke et al., 2005; Perkins et al., 2011). Conversely, a competitive scheme, the 'Rural Priorities' programme, is designed to answer regional needs but requires more challenging plans and higher levels of financial support. In addition, the voluntary nature of such schemes infers the reliance on farmer decisions to achieve targets. It is therefore essential to understand how farmers make these decisions and what factors underlie their judgement in order to maximise the uptake and effectiveness of the measures.

Within the AES, ecological enhancement is one tranche of the schemes offered, though the majority have focused on management for water and soil quality, with ecological benefits sometimes a secondary, non-specified, benefit (Agra CEAS Consulting, 2005). Within the SRDP, a small number of schemes, which are directed at specific species, e.g. corncrakes, or practices, e.g. provision of winter cover, could be classified as a Ecologically-Related AES (ER-AES), and are seen, within this paper, as a sub-set of the suite of AES offered within the SRDP. Consequently, balancing the ecosystem services that could be supported on farmland and those promoted by policy-makers also further complicates farmer decision-making. An understanding of farmers' ecological perceptions and reactions to external pressures is therefore essential for anticipating changes in management and uptake of future AES that impact ecological functions.

3. Materials and Methods

3.1 Study site

The Lunan catchment, a mostly intensively cropped catchment in Angus, on the east coast of Scotland is one of the few places in Scotland that is conducive to supporting intensive cropping, due to a relatively flat and fertile soil. Around 115 farmers manage the 132 km^2 catchment. The main farming systems are general cropping (40%), mixed farming (29%) and cereals (10%) (June Agricultural Census (JAC), 2007). Principally this is a cropping catchment, with only 4% of the total area designated as permanent grass and rough grazing.

Since 2003, the catchment has been designated as a Nitrate Vulnerable Zone (NVZ), which imposes structures on farmer management and production behaviour in relation to organic and non-organic nitrogen use and storage. In addition, it formed part of the Scottish Environment Protection Agency's Monitored Priority Catchment Project that aimed to establish monitored baselines against which the effectiveness of diffuse pollution mitigation measures could be assessed. Thus, it has been a catchment of some concern for policy makers. Accordingly, this study widens the current understanding on the catchment by proposing a distinctive survey on farmer perceptions towards birds, as opposed to more general aspect of decision such as water issues.

As for most intensively managed areas within Europe, this region of Scotland receives on average a national maximum level of £200 per hectare from the Single Farm Payment (Buchan et al., 2010) and of £60 per hectare from the SRDP (RERAD, 2008), the average for Scotland being £110 and £8 per hectare respectively (European Commission, 2009). Accordingly, the high level of government support further increases the relevance of this catchment to understanding how farming decision-making and behaviour can be influenced by ecological perceptions.

3.2 Telephone survey and Analysis

A questionnaire, based on previous Scottish-related studies (Willock et al., 1999a; Sutherland, 2010; Sutherland et al., 2011) was conducted over the summer 2009 and targeted at the main decision maker of the farm business[4]. The questionnaire was initially reviewed by social scientists and agricultural experts and piloted on a small number of target farmers. The questionnaire included several sections: (1) socio-demographic variables, (2) attitudes towards farming, birds and ER-AES, (3) objectives in farming and motivations for AES participation, (4) management intentions, and (5) information sources and themes.

[4] The survey was carried out by an external company. The data were received in SPSS format with basic scorings. No transcription of the interviews was available, which limits the use and interpretation of the data.

The respondents were given a number of statements for which they were asked to answer along a five-point Lickert scale. This allowed quantitative analysis to understand broad trends in attitudes and behavioural intentions. Descriptive statistics were computed using PASW 17.0 (SPSS Inc., 2009) and the use of these scales makes it possible to apply statistical methods adapted for interval data (Diekhoff, 1992; Falconer, 2000; Greiner et al., 2009). A chi-square test was performed to find potential differences with regard to the socio-demographic data collected during the interview. Furthermore, the ecological factors were tested against components of farm management intentions, using principal component analysis. The validity of the underlying components was given through a Kaiser-Meyer-Olkim test (KMO) (Kaiser, 1970), which should be above 0.6 to be accepted (Kaiser, 1974). Subsequently, a set of non-parametric Kendall Tau correlation tests was performed between the management intention components and the other questionnaire statements. Non-parametric tests are best suited to social data such as Lickert scales and for smaller samples (Howell, 1997; Field, 2009).

4. Results

4.1 Respondents Profile

The Scottish Government provided the contact details of 90 farmers within the catchment. This was to avoid cross-surveying with other studies carried out at the time this questionnaire was initiated. Of these 90 farmers contacted, 46 questionnaires were fully completed (giving a response rate of 51%). Table 2.1 shows how these compare to the whole catchment, and a chi-square test indicated a robust representation (at 5% significance) across farm type and size characteristics.

Table 2.1 – Characteristics of the Lunan catchment and the surveyed sample (source: JAC, 2007)

		Lunan Catchment 2007	Sample 2007
Total size (Ha)		13,200	2,868
Number of farmers		115	46
Frequency of farm types (%)	General cropping	40	37
	Cereal	10	9
	Mixed	5	4
	Grass & rough grazing	30	36
	Cattle & sheep (non LFA)	8	11
	Specialist poultry	4	2
	Horticulture	3	2
Area used by each farm type (%)	General cropping	85	74
	Cereal	9	8
	Mixed	1	9
	Grass & rough grazing	2	4
	Cattle & sheep (non LFA)	2	5
	Specialist poultry	<1	<1
	Horticulture	1	<1
Average farm area (Ha)		73 (SD 109)	63 (SD 69)

The vast majority of surveyed farmers are male with a mean age of 55[5]. Most farms are owner-occupied (83%) while few are partly owned with additionally rented land (13%) and only a small amount is fully rented (4%). The majority of farmers (63%) have more than 20 years experience in farming, whereas a further 20% have between 11 and 20 years, and the remaining 13% have less than 10 years experience.

An important dimension to understanding their attitudes is to explore the level of public subsidy given to these farmers. Due to concerns over privacy these had to be allocated to three categories (<50%: 50%, 50-75%: 15% and >75%: 33%). Around 30% of respondents claim to have a non-agricultural diversified business on their

[5] Respondents answered on a five-measure age categories (18-25, 26-35, 36-50, 51-65, 65-90). The calculation of the mean age assumes an even distribution of data within each category.

farmland (i.e. bed & breakfast or horses riding). Also, only 28% are members of a conservation organisation. A total of 40% of the farmers within the sample have participated in AES in the past 5 years (mainly the Rural Stewarship Scheme and Land Management Contracts Scheme).

4.2 Attitudes

4.2.1 General attitudes towards farming

Farmers were asked to highlight the importance of certain factors that underlined their attitudinal approach to farming (Table 2.2). It is important to ask questions on the general context of farming for assessing its importance in the balance of decision-making.

The most significant factor was the satisfaction towards a 'tidy' landscape, followed by the factor "lifestyle" (i.e. household, freedom to decide, living environment). The least significant factor was the need for producing, which is seen generally as an important aspect for the survival of the business. The latter aspect of decision-making is particularly important for farmers running larger farms (>50Ha; χ^2 (8) = 21.386, $p<0.01$), for those who rely mainly on income from non-diversified farming activities (χ^2 (6) = 46.276, $p<0.001$), and for those farmers with a longer farming experience (χ^2 (8) = 57.237, $p<0.001$).

Many studies have previously shown the importance of landscape features, especially for UK farmers (Oreszczyn and Lane, 2000; Fish et al., 2003; Burton, 2004; Hanley et al., 2009; Sutherland et al., 2011). However, there is some dissonance between a so-called tidy landscape and maximising ecological benefit (Carr and Tait, 1991; Burgess et al., 2000; Ryan et al., 2003), e.g. leaving land unmanaged (i.e. untidy) increases the chance of winter survival for corn buntings (Moorcroft et al., 2002). In this respect, a strong desire for keeping land under conventional agricultural production and the social pressure for maintenance associated with it, could be quite a significant barrier to the implementation of ER-AES. In addition, farmers often define a significant dimension to the "good farmer" concept as the management ability to obtain and maintain high yields (Burton, 2004; Burton et al., 2008). In the

Lunan, 61% and 52% of the farmers strongly agreed with the need for maintaining tidy landscapes and for producing respectively, suggesting resistance to behavioural change directed at ecologically-related management.

Other studies have identified "lifestyle" as a major motivation for farming (Willock et al., 1999; Burton, et al. 2008; Barnes et al., 2011a). The appeal for the freedom to make decisions represents a barrier to AES participation since it has been reported in many studies that the constraints of a lengthy contract and the complexity of paper-work discourages most farmers from participating (Wilson, 1997; Ruto and Garrod, 2009; Christensen et al., 2011).

Table 2.2 – Responses given to "attitudes towards farming" statements (%)

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree	Mean St Dev
Maintaining a tidy landscape is important for me and the community	2.2	8.7	-	28.3	60.9	4.24 1.16
Best thing in farming is the lifestyle	8.7	19.6	-	26.1	45.7	3.80 1.42
Need to produce to survive	21.7	10.9	4.3	10.9	52.2	3.61 1.69

4.2.2 Perceptions of the environment as a creator of bird habitat

Lunan farmers generally express concerns towards the environment as a bird habitat *per se* and do claim to integrate it within the process of decision-making (Table 2.3). The perception of the natural environment and responsibility towards maintaining its environmental quality are strongly recognized among the respondents. Birds are generally accepted by these farmers and are seen as part of the farm environment. However, the respondents seem rather optimistic about bird population trends, even though some species are still declining in Scotland (e.g. the lapwing and the grey partridge (Risely et al., 2010)). Moreover, their responses to questions related to bird habitat requirements reveal an inadequate understanding of wildlife habitat quality.

Juntti and Potter (2002) argue that the optimism towards bird population trends is an artefact of the advertisement of a scheme which is formulated in a way that income support is the most attractive feature rather than the ecological benefit it is designed for (see also Burton and Paragahawewa, 2011). Moreover, a range of studies have found that a lack of knowledge concerning bird population trends and some misinterpretation of habitat requirement may limit farmers' sense of responsibility and their willingness to adopt AES (Jacobson et al., 2003; Smallshire et al., 2004; Herzon and Mikk, 2007).

The results of the survey also show that opinion and criticisms about ER-AES are varied. There are mixed perceptions about the benefit of ER-AES to birdlife, translating a lack of direct information about the ecological outcomes of agri-environmental measures (AEMs). Both the statements that relate to barriers on implementing ER-AES, i.e. sufficient information provision and the risk associated with AES, are negatively perceived by almost half of the respondents, particularly those less experienced farmers (χ^2 (4) = 16.827, $p<0.01$). Moreover, a large portion of respondents (63%) agreed that ER-AES should be more flexible, in particular past adopters of the AES (χ^2 (2) = 6.562, $p<0.05$).

The importance of efficient information provision for farmers (Wynn et al., 2001) and the consideration of risks associated with the application of specific measures (Herzon and Mikk, 2007) have proved to be a precursor of AES participation. In addition, other studies claimed that farmers require scientific background information explained to them in a realistic way with comprehensive local and time-specific guidance (Clark and Murdoch, 1997; Ahnstrom et al., 2009).

Demand for more flexibility in ER-AES has been found in other studies (Wilson and Hart, 2000; Manley and Smith, 2007; Scottish Government, 2009a). The restrictions of these schemes, which often require a 5 year agreement, is often perceived as a possible restriction on farmers ability to fully respond to market and weather conditions, and thus to optimise production. However, it could be argued that, historically, habitat creation has generally occurred on the non-productive land or in particular areas where it is deemed hard to farm (Kleijn et al., 2004; Deuffic and Candau, 2006).

Table 2.3 – Responses given to "attitudes towards the environment and ER-AES" statements (%)

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree	Mean StDev
As a farmer I feel close to nature	2.2	6.5	-	19.6	71.7	4.52 0.96
Farmers have a responsibility towards the quality of ecosystems	-	-	-	30.4	69.6	4.70 0.46
Switching from crop to grass negatively affects birds	26.1	30.4	26.1	15.2	2.2	2.37 1.10
Low heterogeneity of crop types negatively affect birds	8.7	32.6	19.6	30.4	8.7	3.00 1.25
Noticed Decreases in bird number in the past 5 years	37	34.8	-	6.5	21.7	2.41 1.57
Birds help lower the number of insects	2.2	6.5	2.2	41.3	47.8	4.26 0.95
I enjoy seeing different types of birds on my farm	-	-	-	23.9	76.1	4.76 0.43
My farm provides a good habitat for birds	-	4.3	-	28.3	67.4	4.59 0.72
There is insufficient information about ER-AES to participate	2.2	45.7	10.9	28.3	13	3.04 1.17
ER-AES deliver long-term benefit to birds	4.3	21.7	10.9	45.7	17.4	3.50 1.15
ER-AES should be more flexible	2.2	15.2	19.6	41.3	21.7	3.65 1.06
ER-AES increase the risk of spreading disease and pest	15.2	34.8	19.6	21.7	8.7	2.74 1.22

4.3 Objectives of the farm business and motivations for AES participation

Farmers were asked to rate a set of social, ecological, and economic related objectives according to their importance for the farm. This is shown in Figure 2.1. The results of this set of statements show the influence of multiple objectives on decisions. On average the farmers prioritise the improvement of wildlife habitats and a range of social parameters, such as time saved for family and social recognition, over standard economic drivers. Farmers seem to integrate environmental considerations within profit goals. The need to break-even is, however, rated as very important, which underlines the issue of farm survival. Despite feeling the need to produce, Lunan farmers do not express this as their main priority, supporting the research emphasis given to external pressures that conflict with personal opinion.

In previous studies farming objectives tended to be generally oriented towards income followed by the maintenance of an acceptable standard of living and by the independence and self-reliance permitted by this type of work (Carr and Tait, 1991; Willock et al., 1999a). Prior to the implementation of EU subsidies and regulations, farmers in the UK were constrained by economic pressure rather than environmental concerns (MacDonald and Johnson, 2000), but Lynne et al. (1995) showed that farmer decision-making also reflects a compromise between private economic goals and local community-based services.

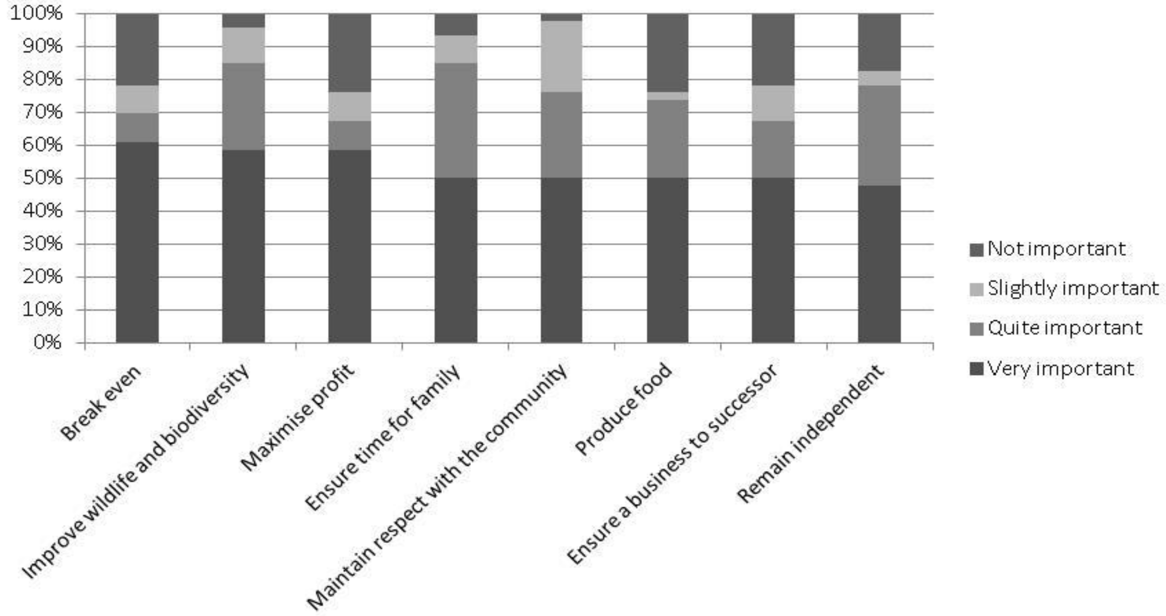

Figure 2.1 - Responses given to “business objectives” statements (%)

The survey reveals that the main motives for participating into AES are intrinsic to the environment (i.e. wildlife, better environment) (Figure 2.2). The financial imperative of AES participation is not highlighted as a binding factor. This is in opposition to other studies that found an equal importance of environmental concerns and financial incentives (Gasson and Potter, 1988; Morris and Potter, 1995; Wilson, 1997; Crabtree et al., 1998; MacDonald and Johnson, 2000; Wilson and Hart, 2000; Fish et al., 2003). A study by Hanley et al. (1999) showed that farming is seen as a source of profit through market opportunities, whilst AES, though a regular income supply, is understood as a source of ecosystem services and a minor fund for further investment. Risk related to the application of AEMs and the level of investment it necessitates should then be a minimal barrier to adoption (Sckokai and Moro, 2006; Koundouri et al., 2009).

However, the “goodness-of-fit” of AES within farm strategy and the positive impact on soil quality had effects for all interviewees, which imply that these farmers strive to picture the necessity for supplying ecosystem services such as wildlife habitat and to integrate it as part of their profession. Farmers therefore perceive the benefit of good ecological land as an opportunity while profit is seen as a need. On the other hand, the main goal in farming is to ensure financial viability (see Figure 2.1), which is maintained through increased production outputs (see Table 2.2).

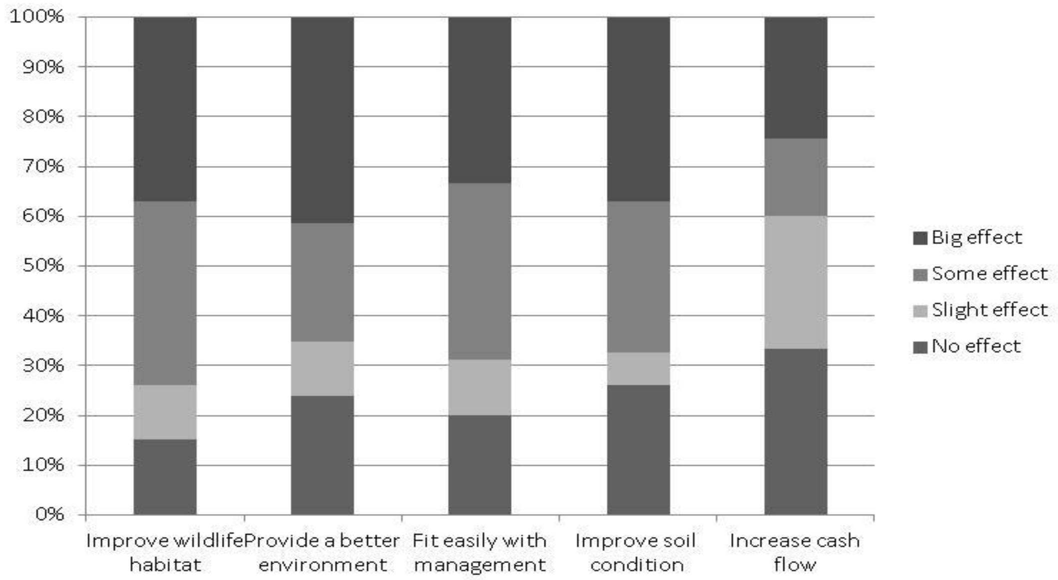

Figure 2.2 - Responses given to "motivation for AES participation" statements (%)

4.4 Management intentions and participation within the ER-AES

The likelihood of carrying out management practices in the near future is given in Table 2.4. Despite the expected consequences of decoupled payments, it seems that the Lunan farmers, who mainly run arable farms, intend to keep the same management practices, with the same production outcomes. Breen et al. (2005) who found similar results for Irish farmers highlighted three potential reasons: misunderstandings towards decoupling, the uncertainty of its long-term practicality and the effect of farmer demographics and farm structure. These barriers are similar to those expressed by the respondents in their attitudes towards participation in ER-AES.

Diversification of the business (i.e. bioenergy crops) does not seem to be a strong option for Lunan farmers. This tends to indicate, once more, that these farmers are rather conservative and generally disinclined to innovate. Bioenergy crops are nevertheless more likely to be adopted by larger farms (χ^2 (6) = 22.046, p<0.001) and by the ones with larger income support (χ^2 (6) = 39.847, p<0.001). Diversification requires a process of innovation where information and experience weigh up the decision towards taking a risk (Pannell et al., 2006), as well as the social norm, which is particularly influential in a small catchment (MacGregor and Warren, 2006). Pampel and van Es (1977) also found that farm size and source of income was good predictor of "commercial innovation".

A number of past studies have shown the positive relationship that exists between innovative farmers and participation in AES (e.g. Willock et al., 1999a; Schmitzberger et al., 2005), and most respondents in this survey do not mention participation in AES as a strong possibility. Risk aversion and cultural pressure might limit innovation and reduce the desire to accept novel ideas. Moreover, the average age of the Lunan farmers (55 years old) could explain the reluctance of farm managers being close to retirement to include new measures and changes within their management plan. However, there is a strong emphasis towards effort that avoids ecological degradation. For most respondents limiting the use of chemicals and ensuring green cover during winter is favourable. Ecologically-friendly farming is represented by most farmers leaving cover during winter, although it is very important for bird survival, farmers might use it as crop protection more than as a conservation measure. Spring cropping is the least likely behavioural intention, which can be explained by the results obtained with winter cropping (i.e. better yield, less risk associated with production and soil protection against erosion). Although ecologists recognize spring cropping as being more suitable for nest establishment by some ground-nesting species (e.g. skylarks (Chamberlain and Siriwardena, 2000)), this information may not necessarily be known to farmers.

Table 2.4 - Responses given to “management intentions” statements (%)

	No	Unlikely	Unsure	Maybe	Strong possibility	Mean St Dev
Keep same practices	15	10	-	20	55	3.93 1.50
Maintain low input system	30.4	6.5	4.3	23.9	34.8	3.26 1.70
Leave winter cover	30.4	13	-	15.2	41.3	3.24 1.78
More efficient machinery	32.6	13	-	26.1	28.3	3.04 1.70
Best yielding variety	37	6.5	-	28.3	28.3	3.04 1.74
Diversify into newer crops (i.e. Bioenergy)	41.3	17.4	-	32.6	8.7	2.50 1.52
Apply ER-AEMs	41.3	23.9	-	21.7	13	2.41 1.53
Plant more spring crops	52.2	26.1	-	8.7	13	2.04 1.44

4.5 Exogenous and informational stimuli

Information gathering is an important behaviour that supports the management decision of a farmer, in particular for considering the issues relating to ecology. In the process of adoption of novel concepts, farmers have to seek knowledge and ideas related to a problem or an opportunity. If a farmer estimates that the information obtained is sufficient to reduce the uncertainty about a given practice, there is a chance for that person to implement this practice. Indeed, a strong background on ecologically-related issues and the relationships with the practices applied can be crucial in farmer decision-making. For that reason, the identification of the sources and themes of information used by farmers is relevant to the study.

Figure 2.3 shows that farmers consult with family members and do not often seek information externally from other sources. This might lead to a significant weakness with accessing up-to-date information.

In terms of issues which farmers look for within the information provided, it seems that both market and ecological related information are the most popular. Alhough, information on policies, new methods of farming and technical information on new crops are only marginally less frequent. Frequent information about market trends also supports the large influence it has on decision-making. The importance of the theme “new farming methods” shows that all Lunan farmers are not totally reluctant to innovate, but do so to improve production.

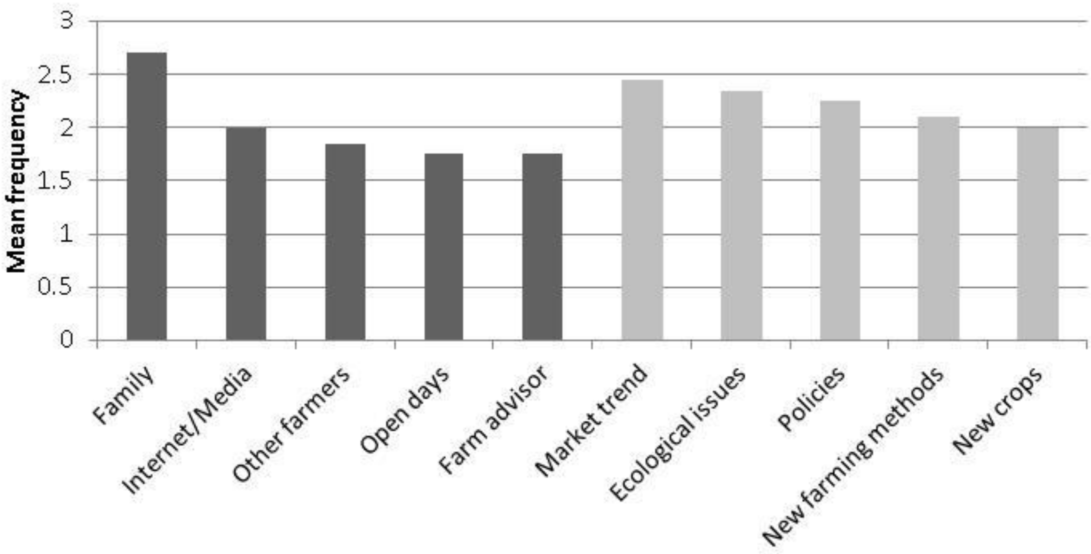

Figure 2.3 – Mean responses for Information sources (in dark grey) and themes (in light grey). A 4-points scale was used in the questionnaire; 1: Never, 2: Occasionally, 3: Regularly, 4: Very frequently.

A set of potential future scenarios that are believed to have important consequences on an ecological perspective was also presented to the interviewees (Figure 2.4). Half the respondents see a positive impact for an increased rate for voluntary ecological-based management and for the viability for producing energy crops. These results seem to highlight a need for financial backing to encourage farmers to apply specific ecologically-related measures. Attitudes towards climate change are varied with around 20% being uncertain towards the consequences on their business. The reintroduction of set-aside scores the lowest in terms of any income effect, with half the respondents not foreseeing any effect, whilst 20% feel that it will have a negative impact on their business.

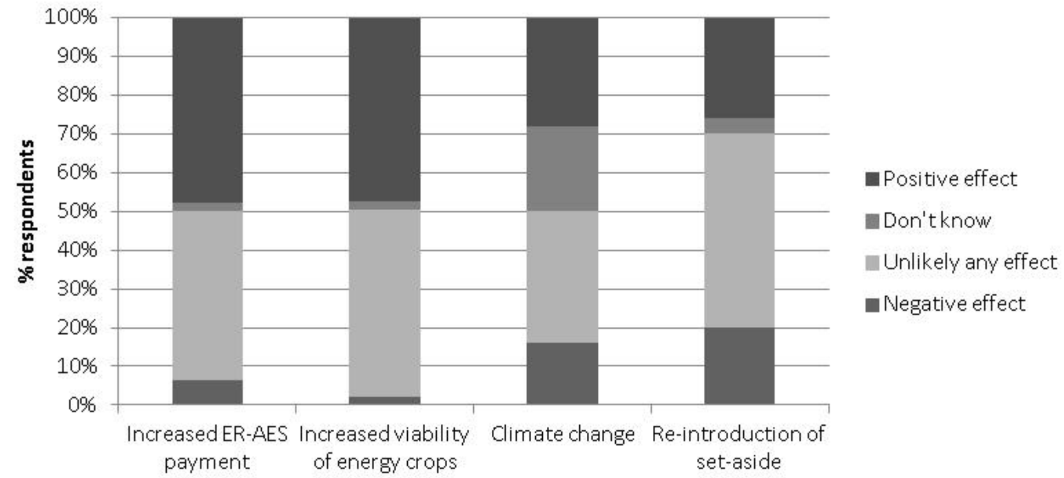

Figure 2.4 – Effect of potential future scenarios on decision making

4.6 Testing the ecological factors with farm management intentions

The relationship between ecological related attitudes, objectives and farm management intentions was explored further through principal component analysis. The analysis provided a number of components with an acceptable KMO statistic of 0.756, and which explain 71% of the variance within the statements. Table 2.5 shows the factor loadings of each "management intention" statement and their relevance in explaining the components. These components are called production orientation, ecologically-friendly management and ER-AES participation (Table 2.5). The component scores were then correlated with other questionnaire statements and explained below (Table 2.6).

Table 2.5 – Rotated component matrix and factor loadings of the "management intention" statements after principal component analysis. The factor loadings in bold permit to depict which statements load on each of the components.

	Business management	Ecologically-friendly management	ER-AES participation
Adopt best yielding varieties	**.822**	.311	
Invest in more efficient machinery	**.748**	.164	.231
Keep same practices	**.740**	.164	-.124
Diversify into new crops	**.728**	.383	.228
Maintain a low input system	.123	**.823**	.200
Plant more spring crops	.248	**.733**	
Leave winter cover	.279	**.660**	.478
Apply ER-AEMs		.199	**.883**

Table 2.6 – Correlation between management intention and other survey statements (Kendall-Tau)

	Business management	Ecologically-friendly management	ER-AES participation
Attitudes			
Need to produce to survive	0.408**	ns	ns
As a farmer I feel close to nature	ns	0.255*	0.277*
I enjoy seeing different types of birds on my farm	ns	ns	0.378**
Birds help lower the number of insects	ns	ns	0.284*
Switching from crop to grass negatively affect birds	-0.240*	ns	ns
My farm provides a good habitat for birds	-0.295*	0.245*	ns
AES should be more flexible	ns	0.267*	ns
Farming objectives (ranking statements)			
Improve wildlife and biodiversity	ns	ns	0.309**
Ensure time for family	ns	ns	0.325**
Maintain respect with the community	ns	ns	0.460**
Break even	0.496**	0.336**	ns
Remain independent	ns	0.232*	0.259*
Maximise profit	0.424**	ns	ns
Produce food	0.331**	0.400**	ns
Ensure a business to successor	0.389**	ns	ns
Motivations for joining AES			
Improve wildlife habitat	ns	ns	0.377**
Provide a better environment	ns	ns	0.383**
Fit easily with management	ns	0.247*	0.257*
Improve soil condition	ns	ns	0.374**

Increase cash flow	0.261*	ns	ns
Future scenarios			
Increased payment for environmental management	0.225*	0.283*	ns
Increased viability of energy crops	0.577**	ns	ns
Reintroduction of set-aside	ns	0.226*	ns

(*: p<0.05, **: p<0.01)

The non-parametric Kendall-Tau correlation coefficients show that ecologically-related attitudes and objectives are a good predictor of management intentions. In general, ecologically-related attitudes, objectives and motivations are positively correlated with less intensive production management.

Production orientation is associated with the belief that production is necessary, and with the objectives of profit making and succession. Crucially, this orientation is associated with a poor understanding of bird habitat requirements. The motivations for AES participation are also profit-related and farmers who intend to apply production-related practices could also be AES participants if the level of payment is profitable to them. These farmers are informed by a variety of sources, mainly media and advisors, on a diverse range of subjects. It would therefore be expected that, when holding negative perceptions of the farm as a habitat for wildlife, the decision maker would continue to apply intensive practices that provide the best profit.

The ecologically-friendly management intention is a good illustration of the conflict that exists between attitudes and objectives. This “dysfunctional perspective toward conservation” (Peterson, 1991) may explain in part the slow uptake of ecologically-related measures. The farmers within this catchment are confronted with personal ideals, which cannot be fully enacted because of the constraints they may face. Ahnstrom et al. (2009) claimed that farmers often choose to manage their land in a way that is “as-good-as-possible” without being tied to further restrictions and costs. This is apparent in the motivation of Lunan farmers for applying AES which should “fit easily within management”, their perception of the lack of flexibility of implementing measures and the potentially encouraging effect of increasing payments for voluntary ecological actions. A positive correlation between the ecologically-friendly management approach and perceptions towards re-applying set-aside found in this survey helps to confirm the statement made by Ahnstrom et al. Furthermore, the cultural significance and potentially current usage of traditional farming practices (e.g. set-aside) might be a further important factor in the uptake of voluntary actions.

The intention to participate in ER-AES is associated with both ecological attitudes and socio-ecological objectives and motivations. The significant correlations between these attitudes and objectives highlight the importance of multifunctionality within the AEMs, i.e. between biodiversity, community services, and management practicality.

5. Discussion

This study has shown that ecological aspects are in general already well integrated into farmer decision-making. There may be some bias from the data collection method, as some authors have argued that telephone and mail interviews can enhance the effect of "social desirability" within statement responses (Kaiser et al., 1999; Maguire, 2009). The positive attitudes towards birdlife were however correlated with the intention to participate in ER-AES, which indicates reliability in the respondent's answers and consistency in both their attitudes towards birds and objectives for the farm.

A number of qualitative studies have provided an insight on the factors influencing the decision to manage the land ecologically or to participate in specific agri-environmental programmes and concluded that ecological interest had a strong positive influence (Schenk et al., 2007; Herzon and Mikk, 2007). The results of the present study offered empirical evidence to support these findings and allowed the identification of patterns in the findings. In particular, the analysis of other aspects of decisions, such as the objectives of the farmer and the motivations for applying AEMs, has highlighted inconsistency between attitudes, objectives and behavioural intentions, showing the importance of financial support and other management related factors.

A minority of Lunan farmers intend to participate in AES in the future. The analysis of the survey demonstrated a lack of knowledge on bird habitat requirements and on the trend of their populations, which may limit the influence on the decision to enter ER-AES, or to apply less intensive management techniques, even if the decision-maker shows interest on the subject. Indeed, an adequate knowledge of these ecological factors could have the effect of reversing the conflict that still exists between some of the economic and non-economic desires within farming. Conversely, the application of ER-AES can influence attitudes towards and knowledge of wildlife habitats. Indeed, a large number of studies have found that participation in agri-environmental programmes enhances the farmer's consideration of ecologically-related aspect of farming (Morris and Potter, 1995; Battershill and Gilg, 1997; Wilson, 1997; Burgess et al., 2000). Though the results presented here have demonstrated that most Lunan farmers already have interest towards questions related to the farm as a habitat for encouraging species. These findings are evidence for the necessity to increase the level of subsidy for expanding the level of voluntary actions targeted at ecological benefits. Specific ER-AEMs are particularly costly to the farmer, and demand a considerable restructuring of his/her management plan. This is why a farmer would more likely apply environmentally-friendly practices which are limited to within the farm rather than additional actions. However, these practices, i.e. providing winter cover, are not sufficient to prevent the breeding performance of some species of birds. Most farmers in Scotland have applied the Land Management Options of the current SRDP and only a small number have entered the more specific Rural Priorities scheme (Cook, 2009). It has been shown how important is the "goodness-of-fit" within management when the scheme demands more focused protocols, such as the options for the conservation of a specific endangered species (Lobley and Potter, 1998; Wilson and Hart, 2000). To meet the challenge of stopping biodiversity loss, the new policies should encourage farmers to apply ER-AES, in particular those measures relevant to biodiversity conservation. Both studies by Wilson (2000) and by Ruto and Garrod (2009) have found uniformity in farmer preferences for the design of AES across Europe. Consistently, farmers claim the need for more financial rewards if the AEMs were to become more complex to apply. This suggests that the policy recommendations proposed in this paper could be applied to wider communities within intensive farming areas.

This study has highlighted the prevalence of perceptions, motivations and behavioural intentions across the Lunan population of farmers. There are similarities in terms of the different aspects of rural development programmes across Europe. For instance, ER-AES options are found in other European countries, e.g. wildlife habitat for red listed bird species in Ireland, extensive cultivation to provide nutrition for Nordic birds in Germany. Therefore, the findings of this study can be applied to other intensive farming areas in Europe, however a similar study could be performed in less intensive areas, which are confronted with different pressures, e.g. more reliance on subsidies, remoteness, smaller capital (Rollett et al., 2008). This is particularly important since these areas presents high natural values and are under the threat of abandonment (Holland et al., 2011).

Our findings also indicate the existence of patterns of behavioural intentions that are linked with specific attitudes and objectives. This draws attention to the different needs and desires to consider when encouraging all farmers within communities to actively apply measures targeted at ecological issues. Farmers who tend to prioritise production and profit-maximisation, especially those with larger farms, won't support the provision of ecologically-related services unless significant financial incentives are offered. Currently these financial supports only cover a part of the costs involved in the application of measures (Barnes et al., 2011b). Therefore, it is expected, that only farmers with strong positive attitudes towards ecology would adopt these measures without any financial rewards, although they have expressed other motivations associated with farm activities (i.e. "goodness-of-fit" and the improvement of soil quality). On the other hand, some farmers intend to reduce the level of chemical input and apply winter cover, but the attitudes and objectives underlying this process are mainly oriented towards production ability and management flexibility.

A large literature exists on farmer typology (e.g. Morris and Potter, 1995; Wilson, 1996; Fish et al., 2003), however, to our knowledge, no typologies are based on ecological-specific perceptions. This kind of typology could enlarge our understanding of decision-making and improve the efficacy of ER-AES design and, crucially, the information that could be tailored to meet particular sets of attitudes and objectives for farming (e.g. Blackstock et al., 2010; Barnes et al., 2011b; Emtage et al., 2006).

6. Conclusion

This paper has applied a fine-grained approach for examining the current status of behavioural intentions related to ecologically-related measures. AES have a range of foci and could be partitioned into discrete sets of ecosystem functions, such as water, soil and biodiversity. This study has focused on the latter, with emphasis on birdlife, and found that participation is strongly linked with the moral consideration for the ecological aspects of farming. Such a finding has importance for the refinement of the future EU rural development strategy. Firstly, farmer decision-making seems to be influenced by the ethical desire for improving the ecological value of their land. This indicates where the design of schemes fails to encourage farmers with strong ecologically-related attitudes, but also those with production objectives. The lack of adequate knowledge on bird ecological requirements and on the current trend of populations appears to be a barrier to ER-AES participation.

In the next reform of the CAP, the agri-environmental measures should be targeted at specific ecological factors such as birdlife, but this will require greater financial rewards. The proposed reform of the CAP for 2013 implies stricter environmental requirements associated with direct payments and a larger share of funds distributed to agri-environmental schemes. Stricter standards of cross-compliance may discourage farmers to apply additional actions, unless these actions have defined purposes, i.e. reversing the decline of bird species. Increasing funds for agri-environmental actions may be an opportunity for narrowing the focus of agri-environmental measures to specific ecological deliverables such as birdlife. If so, ER-AES should provide the participants with knowledge on current trends of populations, and on the positive and negative impacts of different management practices on birdlife. Moreover, there is a need for costly assessment of the ecological effectiveness of the measures, which should be reported back to the farmers.

In general, farmers in the Lunan Catchment are all potential ER-AES participants. Each has different needs that intricately respond to their often-conflicting attitudes and objectives, the network of information they use and the level of influence from external factors. There is a small chance that the Lunan will see dramatic change in land use, nevertheless changes in perceptions and in production systems are more likely to occur. With climate change issues and food supply being at the top of global political priorities, it is necessary to consider how biodiversity targets can be met and whether this is achievable through adequate ER-AES design.

Chapter 3

Farmer perception-based typology

Adapted from Guillem, E.E., Barnes, A., Rounsevell, M.D.A., Renwick, A., 2012. *Refining perception-based farmer typologies with the analysis of past census data.* Journal of Environmental Management 110, 226-235.

Abstract

Perception-based typologies have been used to explore the decision making process of farmers and to inform policy design. These typologies have been criticised, however, for not fully capturing true farmer behaviour, and are consequently limited for supporting policy formulation. We present a method that develops a typology, using a social survey approach based on how farmers perceive their environment (e.g. birds and agri-environmental schemes). We then apply time-series census data on past farm strategies (i.e. land use allocation, management style and participation into agri-environmental schemes) to refine these typologies. Consequently, this offers an approach to improving the profiling of farmer types, and strengthens the validity of input into future agricultural policies. While the social survey highlights a certain degree of awareness towards birds with respect to farmer types, the analysis of past farm strategies indicated that farmers did not entirely follow their stated objectives. External factors such as input and output price signals and subsidy levels had a stronger influence on their strategies rather than stated environmental and social issues. Consequently, the refining of farmer types using this approach would aid the design of policy instruments, which integrate ecological issues within planning.

Keywords: Farm strategy, Farmer typology, Agri-environmental schemes, cluster analysis, agricultural census data, CAP

1. Introduction

Changes in farm strategies are expected after 2013 with the "greening" of agricultural policies and the increasing social and market pressures (Fairweather et al., 2009). Farm strategies (i.e. land use plan, management style, participation into agri-environmental schemes (AES)) are diverse, even at small geographical scale, which highlights the importance of internal factors, such as attitudes and objectives, in decision making. A number of studies have focused on these factors and how they relate to behavioural intentions (e.g. Garforth et al., 2006; Herzon and Mikk, 2007; Gorton et al., 2008; Jongeneel et al., 2008; Barnes et al., 2009; Sutherland et al., 2011). Taking account of the heterogeneity in farmer decisions has improved the relevance of policy formulation and has been the motivation behind the rising development of farmer typologies (Schmitzberger et al., 2005; Emtage et al., 2006, 2007; DEFRA, 2008). These typologies have addressed CAP reform (Gorton et al., 2008), conservation behaviour (Schmitzberger et al., 2005; Davies and Hodge, 2006; Siebert et al., 2006) and wider land use issues (Barnes et al., 2011a; Sutherland et al., 2011). Each of these studies has brought important information for enhancing the effectiveness of policies through the investigation of groups of farmers with similar reactions to exogenous factors and tendencies towards future planning (i.e. Emtage et al., 2007).

To a certain degree, the use of typologies is limited by a lack of robust validation. Vanclay et al. (2006) expressed concerns about the validity of perception-based farmer typologies in policy formulation. They claimed that farmers do not specifically identify themselves within pre-defined groups (also see Fairweather and Klonsky, 2009) and that they can distort their answers in the interest of "social desirability" (Maguire, 2009). Moreover most typologies are generated at one point in time when the future dynamics of strategies could be better anticipated if we distinguish the evolution of trajectories in farm strategies (Landais, 1998; Davies and Hodge, 2007; Iraizoz et al., 2007). Commonly, qualitative analysis is associated with a positivist approach in the sense that it permits a better understanding of the variations that exist within different types; in other words this implies a validity assessment (see Ritchie and Lewis, 2003, p. 40-44). However, this is impractical from a policy-formulation viewpoint, as qualitative assessment does not allow robust application of information and policy at a national level. Another way of validating and refining a typology, and probably the most relevant, is the evaluation of consistency with other studies in conjunction with the appraisal of actual behaviour.

Actual behaviour has not been included into research with attitudinal typologies, despite an apparent need for a more robust understanding of farmer decision making. Data on self-reported past farming strategies across time (e.g. census data, farm account survey, Integrated Administration and Control System (IACS)) are appropriate for the appraisal of actual behaviours. Firstly, this type of data is readily available, and we can assume that the information contained within it is, at least, partly explained by the current typology of attitudes and objectives. In addition, it is possible to quantify information at farm or parcel level, e.g. area under a certain land use, amount of payment from subsidies, and therefore allows us to observe behaviour that are not obvious from the social survey results. In this sense, the analysis of past data is not simply a tool for validation, but represents a means of improving the different profiles of a typology by revealing possible gaps and misinterpretation from social surveys alone. Therefore, the combination of two quantitative methodologies, one to generate a typology from attitudinal statements and one for the appraisal of past farm strategies across time, would contribute at maximising the potential utility of this methodology and making its application broad-ranging. The bulk of typologies have usually concentrated on behavioural intentions and perceptions (e.g. Beedell and Rehman, 1999; Rehman et al., 2007; Anhstrom et al., 2009) although some studies have focused exclusively on farm strategies (Primdahl, 1999; Bohnet et al., 2003; Dannenberg and Kuemmerle, 2010). No studies have tried to bring these two approaches together.

Because of the restructuring of the Common Agricultural Policy (CAP) in 2013 and the transfer of funding from direct payment (Pillar I) to Rural Development Programme (RDP, Pillar II), it is important to understand farmer attitudes towards ecological issues, along with their business objectives and behavioural intentions, which can often be conflicting (Willock et al., 1999; Wallace and Moss, 2002). To assess these conflicts, that are not always apparent from the analysis of social surveys, the use of past data on farm strategies should allow the evaluation of the strength that internal and external factors have on actual decisions.

Consequently, the aim of this research is twofold: i) to develop and describe a conventional catchment level farmer typology based on the perceptions they hold towards ecological conservation, in particular birds, and their farming goals and, ii) to refine these types through the analysis of respondents' past farming strategies obtained from census and IACS data. Identifying farmer beliefs and refining these types for more accurate measurement will serve as a basis for the improvement of future policy, in particular in the transfer of information and its effective targeting for the uptake of voluntary environmental schemes.

2. Materials and Methods

2.1 Study area

Scottish agricultural landscapes are largely composed of hills, upland and unimproved grasslands that are difficult to manage (JHI, 2008[6]). However intensive arable farming is possible, mainly on the East coast of Scotland, due to a better climate, and a relatively flat landscape and fertile soil. Therefore in these areas, agricultural subsidies are at the highest levels, and farmers can adapt more easily to market signals (Wilson, 2011; McCracken and Midgley, 2011), which in turn can influence strongly the decisions on farm strategy. It is from this landscape that the study catchment, namely the Lunan, was selected. The Lunan has been previously studied as it represents an example of a priority monitored catchment and shows environmental fragility, in particular in terms of water and air quality (Vinten et al., 2010)[7]. Since 2003, the catchment has been designated with Nitrate Vulnerable Zone (NVZ) status, which requires specific land management practices (Scottish Executive, 2003). Due to the priority monitored status, census and IACS data were readily accessible. Past studies of this catchment have mainly focused on water issues, therefore this study provides benefits to policy makers in obtaining additional information on farmer perceptions within this catchment of other ecosystem services, such as the maintenance of habitats for farmland birds.

The region comprises 12 parishes and 350 active farmers managing 347 km^2 of arable land[8]. Farmers in the catchment share relatively similar biophysical

[6] James Hutton Institute, Aberdeen, UK. Land Capability Maps, available at: http://www.macaulay.ac.uk/explorescotland/lca.html
[7] See also: http://www.programme3.net/water/Lunanthirdyearreport3.pdf
[8] In this chapter, the catchment area used for analysis of past census data is larger than the area considered in other chapters. This is because census data are given at the level of entire parishes, therefore the area of the catchment under study is enlarged to include parish boundaries.

conditions, agricultural activities and market prospects, making it an appropriate level of study to avoid bias from variation, which may occur at larger scales.

2.2 Generating the typology

The methodology applied here follows two steps: Data collection through questionnaire, data analysis and data reduction techniques, namely Principal Component Analysis (PCA), and hierarchical clustering analysis (Kobrich et al., 2003; Gorton et al., 2008).

A questionnaire was developed to capture perception variables within the study area. This was based on a number of past surveys, which objectives were to identify patterns in farmer attitudes, goals and behaviour, and to build a typology based on these factors (Fairweather and Keating, 1994; Willock et al., 1999; Sutherland et al., 2011). The questionnaire comprised four sections: (i) socio-demographic variables, (ii) attitudes towards farming and bird habitat, (iii) objectives in farming, and (iv) management intentions. The environmental attitudes focused on birds, which have been shown particularly relevant to the case study and translate the moral considerations of the environment as opposed to utilitarism (Guillem and Barnes, forthcoming).

The respondents were given a number of statements, which they were asked to answer along a five-point Likert scale. The use of Likert-scales makes it possible to transform questionnaire responses into quantitative measures (see Robson, 1993) and to use statistical methods adapted to interval data (Diekhoff, 1992; Falconer, 2000; Greiner et al., 2009). Statistical analysis was carried out using PASW 17.0 (SPSS Inc., 2009). Cross tabulations and chi-square were performed to test the relationship with farm structure and socio-demographic variables.

The questionnaire was reviewed by agricultural consultants operating within the Lunan catchment and then piloted on a small number of farmers. A telephone survey was then conducted over the period June-August 2009 targeted at the main decision maker of the farm business. Due to financial limitation and to avoid cross-surveying with other studies taking place in the monitored catchment, only a small sample of 90 farmers was randomly selected from among the entire area base using June Agricultural Census (JAC) data.

In total, 46 completed surveys (a response rate of 51%) were obtained. The small sample population is adequate in supporting the exploratory nature of this research, which is at the catchment level and hence offers only a small population to sample from. The catchment-led approach adopted here means that smaller samples are collected and analysed compared with national scale studies. A number of typologies have been developed using smaller subsets of the population (e.g. Fairweather and Keating, 1994; Brodt et al., 2006; Hall, 2008; Bumbudsanpharoke et al., 2009). The main characteristics of the farmers surveyed and of their farm structure are summarised in Table 3.1.

Table 3.1 – Main characteristics of the sample surveyed, frequency and mean levels

Gender	Male: 80%, Female: 20%
Age	26-35: 9%, 36-50: 28%, 51-65: 37%, >65: 24%
Education	Secondary: 39%, College: 37%, University: 22%
Farming experience	≤10 years: 13%, 11-20 y.: 20%, >20y.: 63%
Ownership	Owned: 83%, Rented: 4%, Partly rented: 13%
Average farm size [a] (Ha)	62.33 (SD 69.07)
ESU [b]	57.09 (SD 82.17)
Farm income	≤50%: 50%, 50-90%: 15%, >90%: 33%
On-farm non-agricultural activities	30% (inc. B&B, horses, game shooting)
Conservation advice received in the previous year	17%
Member of conservation organisation	28%
Past AES participation	41%

[a] Data taken from JAC 2007
[b] ESU stands for European Size Unit and is equivalent to 1200 euros. The values are average taken from JAC 1995 to 2007

The PCA technique allows the reduction of a large number of questionnaire statements for further analysis and the investigation of the underlying structure among them. This was carried out for items related to attitudes towards bird habitat creation and objectives in farming. After selection of the items (assessed through a goodness-of-fit index (Kano and Harada, 2000) and communality values (Hair et al., 2010), a PCA with Varimax rotation was performed. The components, or factors, with Eigenvalues higher than 1 were retained. The factors are defined by questionnaire statements for which factor loadings are greater than 0.45 (Comrey and Lee, 1992). The loadings are correlation coefficients between statements and factors, therefore they indicate the contribution of a statement in defining the factor. Respondents' scores on each factor are directly computed in PASW and provide information about the importance an individual place on the factors.

To measure the strength of each factor obtained, a Cronbach's alpha was calculated and the following scale was used in assessing the result: 0.9: excellent; 0.8: Good; 0.7: Acceptable; 0.6: Questionable; 0.5: Poor; and <0.5: Not acceptable (George and Mallery, 2003: p.231). A Kaiser-Meyer-Olkim (KMO) test was carried out, which measures the partial correlations among variables and, if these correlations are small, demonstrate the validity of PCA for the data (Kaiser, 1970).

The respondents' scores on each factor are used in a hierarchical cluster analysis with equal weight to define the typology of farmers from multidimensional data. Hierarchical clustering is appropriate for small sample sizes and does not require a prior hypothesis (Adams, 2003). The objective was to obtain groups of farmers in the study area with similar attitudes and objectives, and to observe their behavioural intentions and other characteristics. For the clustering process, variable selection is an important phase because of the various influences on farmer management decisions (Emtage et al., 2007). Multicollinearity is also an important issue in cluster analysis, therefore variables that are not strongly correlated to one another should be used. The use of factor scores calculated from the PCA reduces multicollinearity problems in the case of orthogonal rotation such as varimax (Ketchen and Shook, 1996; Field, 2009: p. 658). It also converts discrete data into continuous values, which is important for this technique (Gorton et al., 2008; Barnes et al., 2011a). Squared Euclidian distance measures of similarity and Ward's method were used to generate clusters that are homogeneous and relatively equal in size. A cut-off level was established subjectively to identify the number of clusters by looking for large distance "jumps" between two adjacent steps on a dendogram (Child, 2006: p.123; Hair et al., 2010). Individuals within clusters should comprise at least 10% of the total available population to be meaningful (Sutherland et al., 2011; Gorton et al., 2008). Anova, Chi-square and Kruskal-Wallis tests of independence were carried out to identify the differences between clusters.

2.3 Analysis of past farm strategies

The June Agricultural Census (JAC; Scottish Executive) is an annual survey of agricultural activities for those registered as managing agricultural land. The census covers the *circa* 50,000 holdings registered in Scotland and has an average response rate of over 70% (RERAD, 2009). The data set gives information at the parish and farm level on farm size, standard gross margin and economic size (ESU)[9], as well as levels of activities. The JAC classifies farms by a number of robust types, e.g. specialist cereals, general cropping etc., which is based on 60% of a particular activity contributing to total gross margin. Table 3.2 compares the respondents to the survey with the JAC results for the same catchment area. A chi-square test indicated a robust representation (at 5% significance) across farm type and size characteristics.

[9] Standard gross margin of a given farm is computed in the JAC in the form of added estimations of each farm activity's standard gross margin. The calculation is based on geographically-specific coefficients scaled to the year 2000, thus allowing for meaningful comparison. These values represent the expected average profit under normal conditions (output value minus variable costs) and should not be considered as actual values. ESUs were therefore provided based on the standard gross margins.

Table 3.2 – Characteristics of the Lunan catchment and the surveyed sample (source: JAC 2007)

		Lunan Catchment 2007	Sample 2007
Total size (Ha)		34,721	2,868
Number of farmers		350	46
Frequency of farm types (%)	General cropping	40	37
	Cereal	10	9
	Mixed	5	4
	Grass & rough grazing	30	36
	Cattle & sheep (non LFA)	8	11
	Specialist poultry	4	2
	Horticulture	3	2
Area used by each farm type (%)	General cropping	85	74
	Cereal	9	8
	Mixed	1	9
	Grass & rough grazing	2	4
	Cattle & sheep (non LFA)	2	5
	Specialist poultry	<1	<1
	Horticulture	1	<1
Average farm area (Ha)		73 (SD 109)	63 (SD 69)
Average ESU		69 (SD 110)	55 (SD 82)

The Integrated Administration and Control System (IACS) was adopted in 1992 by the European Commission for improving the traceability and efficacy of payments made to farmers. In order to receive subsidy, farmers must complete a series of forms, related to activity levels within each field and also for each subsidy received, related to both Pillar 1 (production-led) and Pillar 2 (AES) payments. The collection of the IACS dataset relating to the respondents therefore provided this study with detailed information on the farms surveyed.

The JAC and IACS data were analysed to quantify the changes in agricultural activities and farming strategies over the 1995 to 2007 period and these changes were then related to the perceptual types derived above. This is possible thanks to a common code between the JAC and the IACS and which allows a link to the past activities declared by the survey respondents.

For each attitudinal type, the analysis of JAC and IACS data permits to assess the level of influence of economic, political and environmental drivers on self-reported past behaviour, and compare it with attitudes:

- The economic aspect was assessed through a linear regression analysis between the proportion of farm area used for cereals (JAC data) against grain prices, fertiliser prices and national subsidy level (Scottish Government, various years). It is common to observe a reaction to prices with a lag effect (Tracy, 1993), therefore prices were considered over a one year lag interval in the regression calculation. If a farm did not grow cereals during the full period investigated, it was removed from the analysis.
- The policy indicator is interpreted as the ratio of subsidy to income (IACS data). The authors separated payments to support agricultural activities (i.e. Arable Area Payment (AAP), Single Farm Payment (SFP)) from the subsidies awarded to agri-environmental measures (i.e. Land Management Contract, Countryside Premium Scheme, Rural Stewardship Scheme and Farm Woodland Payment).
- Finally, we considered the ecological aspects of farm strategy by carrying out a Johansen cointegration test between the average ratio of arable to grass area and the proportion of set-aside.

3. Results

3.1 Underlying attitudes and objectives factors

3.1.1 Attitudes towards farming and farmland birds

The PCA identified 18 items that were associated with attitudes towards the ecological aspects of farming in the questionnaire. A stepwise variable selection was carried out in order to increase the goodness-of-fit of the model. The procedure led to the loss of 7 items leaving a total of 11 variables under the PCA. The remaining model had a goodness-of-fit index, which represents the overall degree of fit, that is, the squared residuals from prediction compared with the actual data, of 0.965 which indicates that the model is robust enough to provide valid factors (Hoelter, 1983). The PCA had a "passable" KMO value of 0.665, which is still sufficient especially in exploratory analysis (Kaiser, 1974).

Four factors had Eigenvalues over Kaiser's criterion of 1 and explained in total 66.7% of the variance (Table 3.3). According to George and Mallery (2003), the strength of factors is rather weak (Cronbach's alpha), but the small number of items could explain this result (see Cortina, 1993).

The first factor was labelled "*Awareness of Environmental Quality for birds*" (AEQ) since it reflects the knowledge that the respondents had about birds and their relationship to farming. The second factor was named "*Understanding of the Need for AEMs to improve bird habitat*" (UNA). Farmers who score highly on this factor believe in the effectiveness of AES to preserve bird habitats. The third factor related clearly to the aesthetic appearance of the landscape in terms of tidiness and more traditional management aspects. It was therefore labelled "*Importance of Landscape Appearance*" (ILA). Finally a fourth factor represented the hindrance for participating in AES due to the lack of flexibility or the eligibility restrictions. We labelled this factor "*Uncertainty about AES*" (UA). This is not a factor that translates negativity towards agri-environmental schemes; it relates to the degree to which respondents are willing to take part in AES, but are not able to do so due to financial or structural constraints. In other words, farmers who score highly on this factor are potential participants who require special attention for future decision making; although poor scores do not necessarily indicate an inclination towards non-participation.

Table 3.3 - Attitudinal factors loadings after Varimax rotation

	AEQ	UNA	ILA	UA
My farm provides good habitats for birds	**.847**		-.141	
Birds can help lower the number of insects	**.705**	.412	.221	-.113
What my neighbour does on his farm influences the quality of the environment on mine	**.551**	.271		
Farmers have responsibility towards maintaining the quality of the environment	**.541**		.313	.237
AES will deliver long-term benefits to wildlife	.233	**.767**	.163	-.220
In the past 5 years I have noticed a decrease in bird population in the region		**.734**		.258
There is insufficient information about AES		**.716**		.417
Maintaining a tidy landscape is important for me and the community			**.902**	
Preserving the traditional landscape in the area is important for me and the community	.177		**.849**	.113
AES should be more flexible for my farm			.188	**.853**
I would uptake more AES if I could	.411	.370		**.573**
Cronbach's α	0.588	0.669	0.747	0.573

Factor loadings in bold (value>0.45) indicate the integration of the variable in a factor.

3.1.2 Objectives in farming

A separate PCA was carried out for 8 objective items. One item was removed that had a very low communality value. The overall analysis gave a satisfactory KMO of 0.774. Two factors had Eigenvalues over Kaiser's criterion of 1 after varimax rotation and explained in total 74.1% of the variance (Table 3.4).

Cronbach's alpha for both factors gave good values. The first factor groups statements related to profit and production, and was labelled "*Profit Orientation*" (PO). The second factor, "*Environmental and Social Orientation*" (ESO) relates to both wildlife and social aspects. The latter was found to overlap in other studies (Maybery et al., 2005; Greiner et al., 2009), showing that "conservation goals tend to be intrinsically anthropocentric and intertwined with the core ethics and lifestyle of the operator" (Greiner et al., 2009: p 89; see also Chouinard et al., 2008; Sutherland et al., 2011).

There was no strong correlation between attitudes and objectives. Only Profit-Orientation (PO) was negatively correlated with the factor "*Awareness of Environmental Quality for birds*" (AEQ) (-0.374*) and both PO and Environmental and Social Orientation (ESO) were positively correlated with the importance of landscape appearance (0.442** and 0.294*). These factors remain useful in the generation of the typology since they are believed to be major drivers behind the application of environmentally-friendly practices (Gallopin, 2002).

Table 3.4 - Objectives factors loadings after Varimax rotation

	PO	**ESO**
To obtain the greatest amount of profit from my resources	**.919**	
To make enough money to keep my family and those I employ comfortable	**.901**	.284
To provide a service to society by producing food	**.810**	.297
To improve wildlife and biodiversity	-.111	**.870**
To maintain respect within the local community	.241	**.790**
To ensure I have time to spend with my family/friends	.372	**.728**
To remain independent and increase my self-reliance	.430	**.632**
Cronbach's α	0.888	0.795

Factor loadings in bold (value>0.45) indicate the integration of the variable in a factor.

3.2 Typology

The scores generated by the PCA were used to estimate the types through hierarchical cluster analysis. This found four clusters to be significantly heterogeneous: Profit-oriented, Multifunctionalist, Traditionalist and Hobbyist (Table 3.5). The relationship between the four types and the PCA factors are graphically represented in a radar graph in Figure 3.1. The objectives and attitudes criteria do not exclusively discriminate types, but instead show varying degrees of importance.

Table 3.5 – Mean factor scores with standard deviation in brackets for each cluster and ANOVA test (Df=3)

	Profit-oriented	Multifunction-alist	Traditionalist	Hobbyist	F ratio
PO	0.422	0.51	-0.19	-1.8	13.615***
	(0.16)	(0.12)	(0.26)	(0.16)	
ESO	-0.74	0.55	0.65	-0.68	11.836***
	(0.22)	(0.13)	(0.15)	(0.54)	
AEQ	-1.02	0.52	0.44	0.89	19.515***
	(0.23)	(0.1)	(0.14)	(0.26)	
UNA	-0.29	0.51	-0.15	0.37	1.739
	(0.25)	(0.22)	(0.25)	(0.61)	
ILA	-0.19	0.33	0.52	-1.61	9.931***
	(0.26)	(0.15)	(0.11)	(0.53)	
UA	0.065	1.09	-0.61	-0.56	10.502***
	(0.21)	(0.14)	(0.21)	(0.41)	

(*: p<0.05, **: p<0.01, ***: p<0.001)

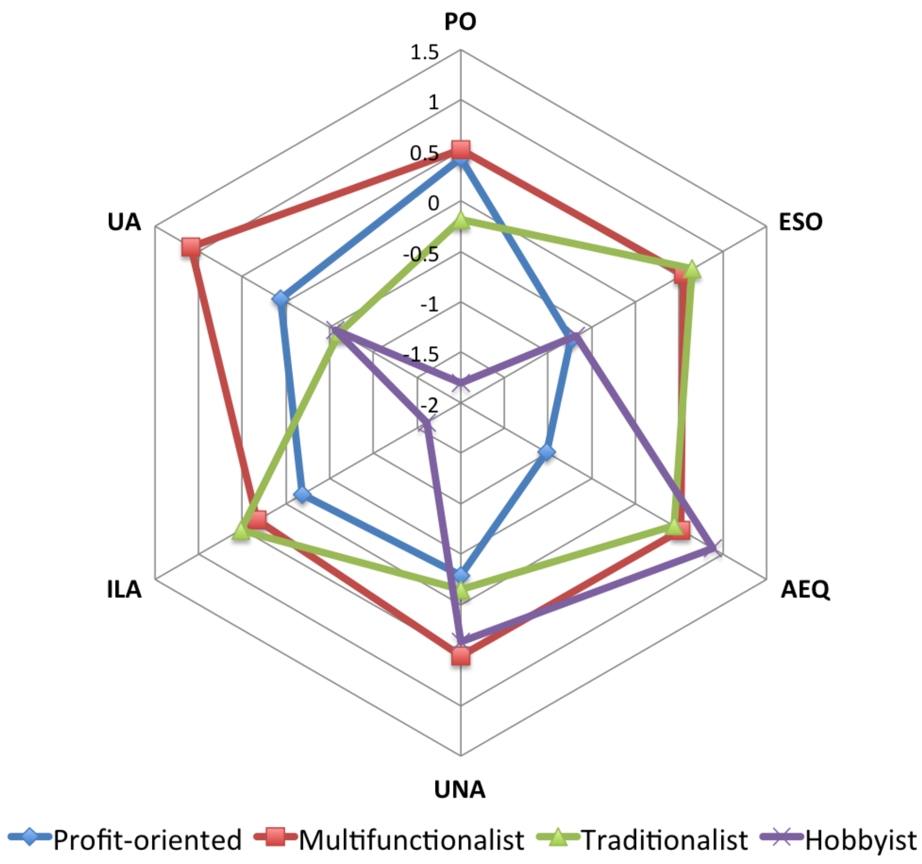

Figure 3.1 - Radar graph showing cluster scores for each factor

Profit oriented (35%)

The first cluster represents farmers who are oriented towards profit maximization with no strong values for environmental and social factors. Their attitudes and knowledge towards the ecological aspects of farming are either negative or completely absent. These farmers also demonstrate a degree of uncertainty about AES highlighting the critical impact of scheme flexibility on decision making. The low score on the UNA factor also suggests that the main motives for applying voluntary measures are financial.

Multifunctionalist (22%)

Farmers within this cluster scored highly in both PO and ESO factors and they are very aware of environmental quality with regards to bird requirements. It is worth noting that they had the most negative perception of the current state of farmland bird populations. This is the only group to have noticed a decline in regional bird numbers in the past five years and around 50% were thinking of providing good habitats for them. They see AES as useful for the delivery of ecosystem services, but disapprove of their current rigidity. The latter draw attention to the issue of scheme flexibility, especially for farmers with high ecological considerations.

Traditionalist (33%)

The "traditional" farmers have an essential orientation to environmental and social values. It has been found in previous studies that traditionalist farmers are more oriented towards social rather than ecological aspects (Davies and Hodge, 2006; Sutherland et al., 2011). Their knowledge and awareness about ecological concerns are relatively high, although they place a great emphasis on the aesthetic qualities of the landscape, which does not always offer benefits to farmland birds (Boatman et al., 2007) and generally these farmers do not sense the importance of AEMs. The fact that they scored low on the "*Uncertainty about AES*" factor demonstrates that the lack of scheme flexibility is not a restricting factor to participation, drawing attention to other causes that could explain the low number of AES participation in the past (40%) and in the future (25%), even though high scores on the AEQ factor implies a willingness to observe good ecological practice.

Hobbyist (10%)

Hobbyists were a small aspect of the Lunan population characterised by a strong interest in wildlife conservation and a high awareness of environmental quality. Landscape appearance is not especially important for these farmers suggesting a deeper knowledge of ecological requirements, which are not associated with a tidy landscape. They understand the need for AES, but do not have this as a particular farming objective. Consequently, they are more concerned about lifestyle rather than business. However, the hobbyist farmers were not considered in any further analysis because of the small number of respondents and the exclusive land use found on their land, e.g. mostly rough grazing.

The three main clusters were compared against the farmer characteristics and farm structure, and management intentions (Tables 3.6 and 3.7). Table 3.6 shows no significant differences in farm and decision maker characteristics across the clusters, apart from the completion of production records, for which the profit-oriented farmers dedicate more time.

Table 3.6 – Characteristics of farmers and their farm structure in the sample, and test statistic (Anova, Chi-square, Df = 2). Standard deviation is given in brackets

	Profit-oriented	Multifuncti-onalist	Traditionalist	Test statistic
Respondent frequency	34.8%	21.7%	32.6%	
Land area covered (Ha)	48%	21%	31%	
Average farm size [a] (Ha)	86.35	59.47	58.6	F = 0.743
	(73.63)	(55.06)	(74.90)	
ESU [b]	71.23	62.71	56.27	F = 1.063
	(59.14)	(57.84)	(87.33)	
Gender Male (%)	94	60	87	$\chi^2 = 5.185$
Over 50 years old (%)	62.5	40	80	$\chi^2 = 4.147$
Higher Education (college and university) (%)	62.5	60	40	$\chi^2 = 1.790$
Highly experienced farmers – more than 20 years (%)	81	50	67	$\chi^2 = 2.804$
Total income from farm (%)	44	33	33	$\chi^2 = 2.645$
Production record (%)	81	70	73	χ^2= 12.004**
Successor (%)	75	50	73	$\chi^2 = 4.342$
Member of conservation organisation (%)	31	40	27	$\chi^2 = 0.495$

(*: p<0.05, **: p<0.01, ***: p<0.001)

[a] Data taken from JAC 2007

[b] ESU stands for European Size Units and is equivalent to 1200 euros. The values are an average taken from JAC 1995 to 2007.

The management intentions are diverse and correspond well with the definition of farmer types (Table 3.7), highlighting the importance of both attitudes and objectives in decision making. A number of practices were significantly assigned to types, mainly these with a positive effect on the environment. Profit-oriented farmers are likely to grow the best yielding varieties and invest in machinery, although with a lower probability; whereas multifunctionalist and traditionalist farmers intend to reduce chemical inputs. In accordance with their farming objectives, multifunctionalists also intend to improve production by planting higher yielding crops and by investing in machinery. Multifunctionalists are willing to apply more agri-environmental measures, whilst traditionalist farmers clearly are not.

The multifunctionalists revealed a greater uncertainty towards changing their current practices. Consequently, multifunctionalists seem the most “innovative”, especially with a relatively high instance of risk-taking (planting new crops). Traditionalist farmers are the most conservative, in accordance with other study findings (Shucksmith, 1993; Walter, 1997). However, they stated that they aspire to reduce input level and increase land area. This conservatism was also found in the profit-oriented types.

Table 3.7 – Mean responses for management intention for each type with standard deviation in brackets and Kruskal-Wallis Test (from 1: Never to 5: strong possibility with 3: neutral response)

		Profit-oriented	Multifunct-ionalist	Traditionalist	Kruskal-Wallis H
Production	Best yielding varieties	3.81 (1.47)	3.10 (1.85)	3.00 (1.71)	1.814
	Invest in efficient machinery	2.88 (1.75)	3.40 (1.51)	3.50 (1.70)	0.787
	Increase land	2.12 (1.36)	2.50 (1.58)	3.00 (1.57)	0.105
Innovation	New crops	2.44 (1.31)	3.00 (1.56)	2.86 (1.07)	0.666
	Keep same management	4.00 (1.41)	3.60 (1.51)	4.43 (1.28)	2.933
Environmental	Maintain low input system	2.69 (1.78)	4.20 (1.03)	3.64 (1.55)	4.814 $p<0.1$
	Apply AEMs	2.19 (1.33)	3.50 (1.58)	2.21 (1.58)	6.348*

(*: $p<0.05$)

3.3 Linking past data to the farmer typology

By using the JAC and IACS data, the three farmer types were examined further in terms of their past agricultural and economic activities. Land use strategies are particularly important when categorising farmers according to their ecological concerns. In this sense, it is possible to test the strength of "ethical" beliefs on actual behaviour (also called "right-based beliefs" by Hanley and Milne, 1996). To that end, we designed three indicators that are comparable between the three main types (Profit-oriented, Multifunctionalist and Traditionalist): namely indexes which reflect the economic, political and ecological aspects of farming.

3.3.1 Farming strategy and economic motives

On average over the period 1995 to 2007, different farming activities seem rather similar between groups. The small catchment area, the climate and topography are limiting factors for any degree of land use heterogeneity. However, some significant differences were found. The main crops planted by the profit-oriented type are spring cereals. Although spring cereals have higher ecological value than winter cereals, particularly for ground-nesting birds (Boatman et al., 2007), they also represent a considerably lower variable cost in production (SAC, Various years) and are less risky due to the variable weather of the region. Multifunctionalists rely on both winter and spring cereals, indicating higher risk taking and possibly mixing high yield from winter cereals with the diminishing cost of spring cereals. Spring cereals, vegetables and potatoes comprise the main land use activities for traditionalist farmers. Vegetables are grown mainly for break crops, family consumption and livestock fodder.

An indicator demonstrating the economic motivation was tested by carrying out a regression analysis between the proportion of cereal area grown on farms (wheat and barley) and the lagged cereal grain and fertiliser prices (Scottish Government, Various Years) over the period 1995 to 2007. However, no significant relationship between the proportion of cereal area grown and the lagged price of cereal grain for either profit-oriented or traditionalist farmers was found. The regression was a rather poor fit (R^2=0.5), but cereal grain lagged prices explained a proportion of the variation in multifunctionalist farms, significant at 0.01%: for 1% increase in grain price, multifunctionalist farmers increased the area attributed to cereal crops by 3%.

Similarly, the profit-oriented type was found to have a significant (at 0.05%) negative relationship with fertiliser prices: for a 1% increase in fertiliser price, the area of cereal crops was reduced by 1%. Consequently, it seems that the multifunctionalist increases the proportion of cultivated area when grain prices increase, but this is not replicated in the profit orientated type who tend to be more conscious of the impact of cost increases, which leads to a reduction in cropping area. Traditionalists were found to be more concerned by the effect of subsidy change, more specifically the value of the arable area payments, significant at 0.01%: a 1% increase in national subsidy that support cereal production led to a 2% increase in cereal crops area. Hence, the income support provided by area payments may be a means of deferring risk for this type.

3.3.2 Policy enticement

The policy indicator is interpreted as the ratio of subsidy to income (Figure 3.2). The ratio of support subsidy to income was in general higher for both profit-oriented and traditionalist farmers. Schmitzberger et al. (2005) also found that “innovative” farmers, such as the multifunctionalists, were characterised by lower dependency on income support. This also suggests that multifunctionalists might follow commodity price trends, apply more intensive management to return better yields, without respecting cross-compliance associated with subsidised crops.

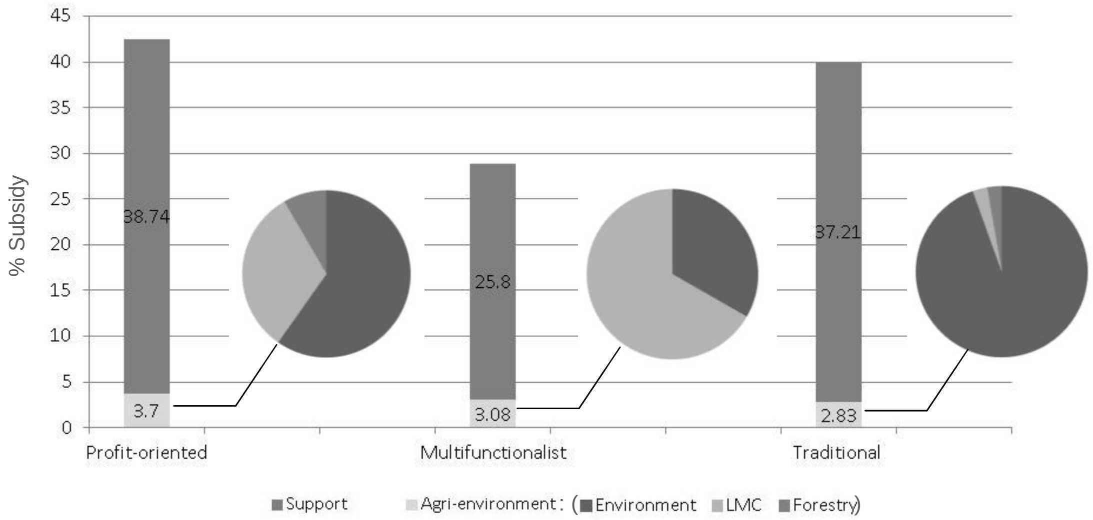

Figure 3.2 – Average proportion of subsidies on total income from 1995 to 2007 (Average for Agri-environmental subsidies is calculated from 2000 onwards and comprises Forestry schemes, Countryside Premium Scheme and Rural Stewardship Scheme (Environment) and Land Management Contract (LMC); General subsidies are Arable Aid Payment until 2004, Single Farm Payment from 2005 and Livestock subsidies such as Beef Suckler Premium Scheme).

The level of agri-environmental subsidies in relation to total income is the highest for profit-oriented farmers, although they adopted these less often than the other types. The reason for this low take up is associated with the low interest in ecological issues, their reluctance to change practices. Indeed, the main motivations for applying voluntary measures are financial and managerial. Other studies found similar styles of participation (e.g. passive adopter: Morris and Potter, 1995; opportunist: Fish et al., 2003). The AES participants within this group are seeking the maximum economic benefit from a scheme and, most commonly, these farmers might register their hedges or winter cover practices as options that they have already applied. The profit-oriented farmers have adopted the Rural Stewardship Scheme (RSS), which is a competitive application. First, the farms within this group are relatively bigger and therefore can allocate more land to AEMs. Second, regardless of stricter requirements, competitive AES can also return better payments (Scottish Government, Various Years).

Of all the types, the multifunctionalists had the highest uptake level of AES in the past (60%) but the ratio of AES subsidy to total income was lower than for profit-oriented. A positive relationship between innovative farmers and participation in AES has been demonstrated elsewhere (Willock et al., 1999a and b; Schmitzberger et al., 2005). Their knowledge about ecological issues and the motivation for improving the environment can explain the non-maximisation of financial return from the application of AEMs. Moreover, this group is also made up of the highest number of farmers who practice game shooting on their land. Measures such as grass margins and beetle banks are particularly appealing to them. This type is similar to the Fish et al.'s "engaged farmers" and Morris and Potter's "active adopters" (*ibid*). However, despite their "engagement", the multifunctionalists have mainly adopted non-competitive schemes such as the Land Management Contracts, which are easier to implement (because less focused).

In the past, 40% of traditionalist farmers in the sample adopted AES. They are unwilling to take up more AES in the future but are motivated to improve the environment, e.g. by using less chemicals. A similar participation style, namely "catalysing", was found by Fish et al. (2003) for which income loss might be limited by applying measures mainly on less productive areas. The ratio of agri-environmental subsidies to total income shows that traditionalist farmers have made the least profitable use of these schemes, and have adopted the more targeted actions from the competitive schemes (i.e. Countryside Premium Scheme and Rural Stewardship Scheme).

3.3.3 Ecologically-friendly practices

Some evidence points to set-aside as having considerable benefits for wildlife (for a review see van Buskirk and Willi, 2004) and it may be expected that farmers with ecological concerns would use set-aside as an "ecologically-friendly" practice. Figure 3.3 shows the relationships between the JAC time-series corresponding to the three farmer types. The null hypothesis that there are no cointegrating relationships was tested using Johanson's test. This hypothesis could not be rejected, although there were some interesting variations, which will be subsequently described.

Multifunctionalist farms have the least proportion of set-aside on their farms despite a high score on the ESO factor and other ecologically-related attitude factors. The proportion of set-aside is following the compulsory rate for profit-oriented farmers. Traditionalist farmers have the highest proportion of set aside. Although these findings show that the set-aside variable is not robust enough to indicate a farmers' ecological dedication, they also allow us to conclude that the ethical trade-off is stretched between the financial incentive and environmental actions. Set-aside also has an economic benefit since rotational set-aside can act as a "management tool" directed at the improvement of crop yield (Crabb et al., 1998; Walford, 2002).

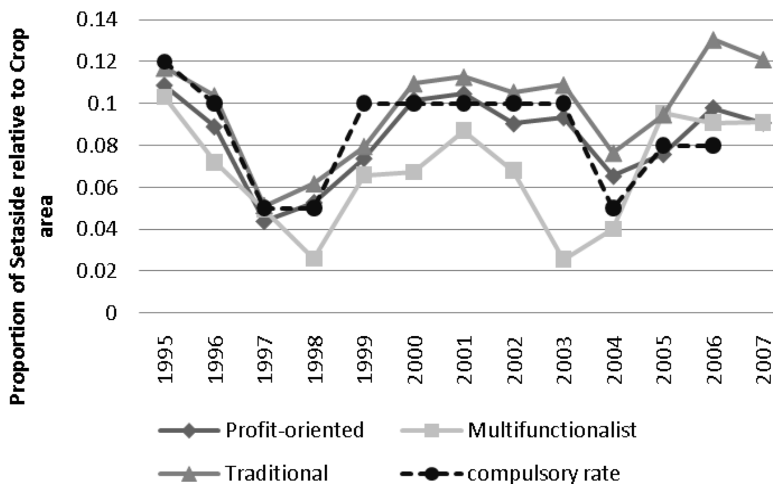

Figure 3.3 – Proportion of set-aside (rotational and non-rotational) relative to crop area for the period 1995 to 2007 (source: JAC)

In the same manner, the ratio of crop to grass area underscores the conflict between economic and social or ecological objectives (Figure 3.4). Here again we could not reject the hypothesis that there are no cointegrating relationships. Traditionalist farmers possess heterogeneous land (with a wider mix of grass and crops). Conversely, profit-oriented farmers cultivated crops on more than 70% of their land over the whole period. The variations in the ratio for profit-oriented and traditionalist farms although seem to be contradictory. When one reacts to prices, the other might respond to the resultant subsidy level. In fact, since decoupling in 2004, traditionalist farmers have decreased the amount of arable area in favour of that dedicated to grass, while the profit-oriented farmers have adapted to the increased prices of cereals (i.e. in the period 2005-2008, the wheat price increased by 127% (Mitchell, 2008)). Variations can be observed in multifunctionalist farms. For instance in 1997-1998, in

2001-2002 and later in 2005-2006, the land allocated to crops was reduced considerably and the amount of temporary grass increased. This seems to indicate some variability in planning, which is particular to this type.

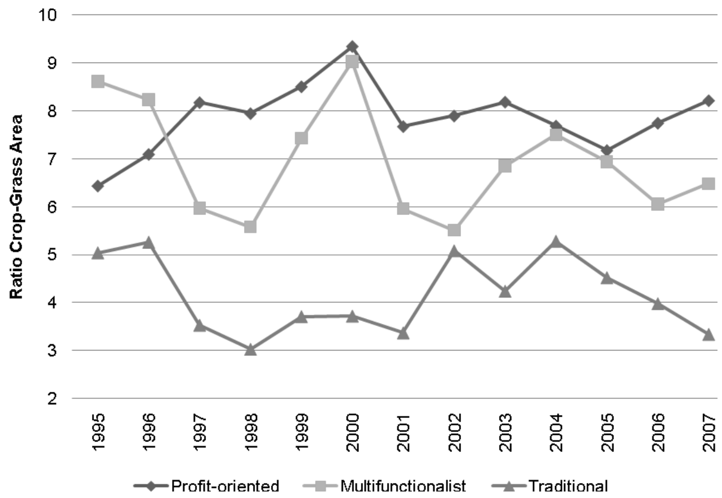

Figure 3.4 – Ratio of crop to grass area from 1995 to 2007 (source: JAC)

4. Discussion

The perception-based typology established from this study shows that farmers in the Lunan catchment have a combination of objectives and values that translate into different strategies. Although all respondents held relatively strong concerns about ecological and landscape issues, a spectrum of varied commitments was evident from the study of past farming strategies. The level of importance of different farming objectives and the actual land use allocation are important farmer type-specific indicators regarding the sense of duty that farmers hold towards the management of the agro-ecological environment.

The first conclusion made after analysing past data from census and IACS is that management strategies can be better explained by the objectives of farming alone rather than by attitudes (or, indeed, a combination of the two). The multifunctionalists are a good example of farmers who apply intensive practices whilst holding very strong positive attitudes towards the ecological aspects of the business, although it could be argued that maximising returns may help with pursuing other goals. Multifunctionalists have a good understanding of ecological processes and recognize the need for applying specific measures, even though they dislike the strict constraints attached to these measures. This was shown by the application to non-targeted options (i.e. Land Management Contracts). The analysis of census data (e.g. economic indicators) has revealed that multifunctionalists react to output prices more than ecological issues and policy incentives. In the current context, where the CAP encourages free market trade and demand more rigorous compliance, these farmers are expected to become less and less dependant on subsidies in favour of applying more profitable (and more intensive) practices. Therefore, while the social survey showed a strong consideration for ecological issues by the multifunctionalists, the analysis of past strategies has highlighted a more accurate behaviour, which is not along the lines of ecological attitudes.

The traditionalists operate relatively extensive management, but environmental conservation remains passive. They are unintentionally the most environmentally-friendly stewards of the land as they have mixed farming activities and use set-aside (see also Schmitzberger et al., 2005). However, the majority do not apply voluntary measures and this rate is declining. They do not benefit from the AES programme nor do they understand its need. Nevertheless, even though a minority, the AES participants within this type have applied specific measures from the Rural Stewardship Scheme. There is a significant difference between willingness to maintain wildlife habitat and acting towards its improvement in this group. Walford (2002) and later Dobbs and Pretty (2004) put forward the distinction between regulations as a way to avoid negative externalities and voluntary measures that produce public goods. They cite the example of Nitrate Vulnerable Zones (NVZs), which are perfectly suited to the Lunan catchment. NVZ regulations have become compulsory, leading to rigid conditions and rearrangement of farming management plans (Barnes et al., 2009). The same observation is made for the conditions under the arable area payment schemes that are close to the management by the traditionalists, i.e. set-aside requirements, field boundaries and timing restrictions (Dwyer et al., 2000). Under these regulations farmers have to consider the cost of polluting water or suffer penalties. Traditionalist farmers have a strong desire for active farming, i.e. production (Fish et al., 2003; Davies and Hodge, 2007), but they also feel constrained and embedded within an environmentally friendly obligation framework (Potter and Lobley, 1992; Wilson and Hart, 2000). This is supported by the high dependency on support payments this group showed. Therefore, future support payments should be stricter in terms of environmental consideration to generate better results from farmers who are not willing to apply voluntary measures. This group of farmers are found to have a strong consideration for social and environmental issues and no strong desire for financial maximisation. However, the strong dependency on support payments (i.e. AAPS, SFP) highlights a way of returning profit, which is not translated into the questionnaire answer. In addition, the fact that they rely more on support subsidies and defer risk associated to price volatility can lead to a better appreciation and concern for social approval and positive environmental feedbacks. These findings raise questions on the future reactions of this type of farmer when funding will be transferred from Pillar I to greening measures, especially when these farmers intend to keep the same management, invest in machinery and increase their land area.

For the profit-oriented farmers, both objectives and attitudes are relatively well translated into their past farming strategy. There is a marked difference between two intensive strategy types, namely multifunctionalists and profit-oriented farmers, where one takes risks in new and alternative farming, the other avoids innovation by switching to familiar plans when input prices increase. The profit-oriented farmers have intensive strategies, low AES uptake and depend highly on direct payment. Despite low AES participation, the analysis of past data has shown that the profit-oriented types have financially benefited from competitive schemes. This highlights the willingness of these farmers to apply specific targeted measures, as long as it is adequately awarded. Therefore it is expected that this type of farmer might adapt in a relatively straightforward manner when the direct payment will decrease if this is to fulfil profit maximisation. In addition, their past farming strategies reveal a tendency to lower costs and to sow spring crops rather than winter, which is beneficial to ground nesting bird species.

The hobbyists have not been included in the analysis due to statistical limitations, yet they are an important group for which the number of individuals is growing (Shucksmith and Hermann, 2002; Mather et al., 2006) and that generate ecosystem benefits (Bohnet et al., 2003). Even the small patches of land they manage in the study area, often rough grazing, act as important sources of biodiversity and contribute to the heterogeneity of the farming landscape mosaic. They may also play a role in the extent to which farming becomes multifunctional; indeed a considerable number of these farms possess horses for public use, which will probably be enhanced in the future if their viability increases. An increasing number of this type of farmer might however lead to a discontinuity between agriculturally-skilled farmers, most notably in the exchange of information (Bohnet et al., 2003).

The pressures of financial survival and resource constraints often exceed environmental and social concerns. This is translated into the relatively low uptake of AES in general. In addition**,** flexibility was seen as an issue in AES application, at least by profit-oriented and multifunctionalist farmers, and this emphasises the poor resulting outcome of these measures. Multifunctionalists hold strong beliefs regarding the importance of AES and are the most likely to adopt them, although they did not demonstrate an efficient use of these schemes in the past. Positive environmental attitudes imply fuller conservation commitment, which improves the results of agri-environmental effort (van Herzele et al., 2011). An issue with conservation commitment, however, is the transfer of production loss to smaller, but intensively productive, parts of the farm (Davies and Hodge, 2007). Profit-oriented farmers on the other hand have a poor consideration towards environmental issues and a strong production orientation, although they have fully exploited AES, and demonstrate the highest level of voluntary subsidies relative to income. Deuffic and Candau (2006) have described two groups of French farmers who seem closely related to the traditionalists and multifunctionalists found in this study. In the first case, traditionalist farmers claimed that low levels of maintenance (e.g. hedgerows, field banks) are part of their work and they should not be compensated for this. Conversely one farmer in the multifunctionalist group claimed that ‘‘you have to live with the times. Before you were paid for what you sold, now you are paid for a service’’ *(ibid,* p.571). This statement portrays how multifunctionalists may comprehend AES, although they did not seem to have delivered many of these “services” yet. AES have also been criticised for their eligibility criteria. Dobbs and Pretty (2004) noted that payments for environmentally driven measures are inequitable, leading to the discouragement of some farmers. The creation of hedgerows, for example is subsidised, while their long-term maintenance, often applied by traditionalist farmers, is not rewarded.

5. Conclusion

The purpose of this paper was to present a typology based on a single period survey of ecological attitudes and farming goals, and then refine this further with respect to time-series data on past farming strategies. This obviates the need for costly resurveying of participants or the development of methods to elicit truthful responses to farming behaviours. The types revealed in the study, at least partially, agree with those of previous work (e.g. Shucksmith, 1993; Fairweather and Keating, 1994; Walter, 1997; Shucksmith and Herman, 2002; Davies and Hodge, 2007; Sutherland et al., 2011). However, the analysis of past census data has permitted further refinement of the typology.

Most farmers in the sample expressed a relative concern towards the environment, and in particular birds, which have been adopted as a biodiversity indicator for policy makers (Gregory et al., 2003). However, despite perceptions and objectives inclined towards ecological and social issues, past farm strategies have demonstrated that in reality activities are not yet carried out entirely along these lines and that farmers largely react to financial signals (input and output prices, support payments). This allows us to consider AES participation as part of the whole farm strategy, including other aspects of production and business survival, as opposed to a distinct decision.

Despite the small number of cases under analysis, the authors encourage the application of this novel methodology to larger scale populations for refining perception-based typologies of farmers, and revealing aspects of decision making that are not obvious from social surveys alone. This will make the use of typologies more valid since it can counteract the issue of "social desirability" and the lack of temporal trajectory, and will more truthfully represent farmers and their needs. Indeed, the findings can have larger repercussions on the policy recommendations inferred from perception-based typologies. Despite strong concerns towards ecological and social issues, multifunctionalist farmers will respond favourably to the relaxation of scheme requirements and to financial incentives. Traditional farmers should be better "prepared" for the future change in CAP, i.e. encourage and reward them to provide services as part of their production. Policies should promote the farm strategies of the profit-oriented farmers, with potential ecological benefits. More information is also needed to increase farmers' awareness and encourage them in a direction that is best adapted to various motives. This requires the application of innovative methods of engagement with the farming population such as tailored information strategies.

Chapter 4

Agent-based model of farmer's decision making

Adapted from Guillem, E.E., Murray-Rust, D., Robinson, D.T., Barnes, A., Acosta-Michlik, L., Karali, E., Rounsevell, M.D.A. *Observation of heterogeneous farm strategies and sustainable trade-offs using an empirically-grounded agent-based model. Environmental Modelling & Software, In review* (2012).

In Chapters 4 and 5, the agent-based model was encoded in Java and run on the RePast Simphony platform of the Eclipse software (open sources). The Aporia model is available at http://wiki.ed.ac.uk/display/ecochangeabm (see also Murray-Rust et al., 2012, In Review). In the CD-ROM, the input data specific to the Lunan catchment are provided in Excel files.

Abstract

Agricultural landscapes provide a wide variety of ecosystem services essential to human welfare. However Land Use and Cover Change (LUCC) leads to uncertainty in the future provision of these services. One of the dominant actors for change in farming areas is the farmer, which has commonly been modelled as a single profit-maximiser. In fact, the internal process of farmer decision making is rather complex and involves different spatio-temporal responses, i.e. policy, market, attitudes, preferences.

This paper aims to observe LUCC in a Scottish arable catchment under different socio-economic contexts, as well as past and potential future policy initiatives from a transparent decision making modelling approach. An agent-based model was used to simulate farm strategy decisions by three attitudinal types of farmers, profit-oriented, multifunctionalist and traditionalist, through a multi-attribute utility function reflecting the type-specific preference structure for the sustainability attributes of alternative strategies.

The results suggest that not all farmers would be satisfied, at least financially, in different socio-economic context; in particular, those farmers with environmental and social goals. The results also highlight the possible consequences of underlying farmer values and, hence, on the effectiveness of policies to support sustainable agriculture. Therefore the proportion of farmer types within a landscape is particularly important to meet specific and sustainable targets. Advisory systems and policy prescriptions need to consider the wider impact on underlying farmer values for encouraging societal demands. Human values and preference structures in modelling LUCC is therefore important for the development and the analysis of such models and allows the analysis of model outputs to identify the winners and the losers in a particular context, and re-balancing the benefits to all farmers.

Keywords: Farmer Decision making; choice-based conjoint; LUCC; Sustainability; Agricultural policy; Agent-based Model

1. Introduction

Agricultural land, which occupies approximately 38% of the World's terrestrial surface (FAO, 2009a), generates food, fuel, fibre and other ecologically and socially-related ecosystem services. This land area is constantly changing due to socio-economic, biophysical and political pressures. This brings uncertainties for the future provision of ecosystem services and, for that reason, the development of adequate policy instruments that meet societal, ecological and biophysical needs is difficult for short and long-term planning.

Farmers, by applying specific farm strategies, are at the centre of the processes underlying land use and cover change (LUCC) and its subsequent effect on the provision and quality of ecosystem services. The understanding and observation of individual farm strategies are therefore essential for tackling future issues concerning the sustainability of agricultural areas. The current knowledge of farmer decision making has reached a remarkable level of detail. The use of theories and methodologies from social sciences, psychology and social psychology has been particularly relevant to reinventing the farmer, formerly a profit-maximiser, into an individual who considers a variety of goals (see review by Garforth and Rehman, 2005), for which trade-offs are made to satisfy the decision maker's interests. This is influenced and constrained by external factors that include, but are not limited by market, policy, and socio-cultural contexts (Lambin et al., 2001). The consideration of multiple attributes in decision making plays an important role in the correct appraisal of possible futures and on the effectiveness of policies targeted at improving sustainability (Cochet and Devienne, 2004; Laoubi and Yamao, 2009).

One approach to modeling complex decisions is to disaggregate the decision process using the principles of sustainability, through which economic viability, social and environmental benefits are assessed by the decision maker (Faucheux and Froger, 1995; Sydorovych and Wossink, 2008). Each decision maker assigns different levels of importance to these principles. The modelling of farmer decision making requires a strong conceptual framework, a variety of data, and the characterization of a high number of individuals. The use of Agent-Based Modelling (ABM) is suitable in dealing with such a high degree of complexity (i.e. multiple scales and organisational levels) and to translate individual choices into higher-level behavioural patterns (Brown, 2006).

The information gained from self-reported data (i.e. social surveys, interviews, choice experiment) can be used in the development of empirically informed ABM, which is the next step in the improvement of the approach (Berger and Schreinemachers, 2006; Aalders, 2008; Rounsevell et al., 2012). Only a few studies have incorporated this aspect in ABM of LUCC models (e.g. Fernandez et al., 2005; Brown and Robinson, 2006; Valbuena et al., 2010a; Chen et al., 2011), but the benefits are numerous (see Lambin et al., 2000; Rounsevell et al., 2003).

This paper aims at observing farmer behavioural change in different socio-economic and environmental contexts and past and potential future policy initiatives. To this end, an ABM is developed that represents heterogeneity in farmers decision making. Agents are represented empirically by using two types of self-reported data (a telephone survey to generate agent types and a choice-based conjoint analysis to represent the subjective sustainable trade-offs of strategic decisions) and which are spatially distributed within a GIS-based representation of an arable catchment. Based on rational choice theory, farmers make individual choices according to their preferences and expectations about the sustainable outcomes of different farm strategies. The changes in land use and management intensity are evaluated up to 2050 under three socio-economic scenarios based on the IPCC-SRES (Nakicenovic et al., 2000). Due to the current pressure from CAP reform and climate change issues, particular attention is paid to the adoption of agri-environmental measures and bioenergy crops that have antagonist consequences for the provision of ecosystem services.

2. Methods

2.1 Study site

We applied an ABM approach to the Lunan catchment, which is located in Angus on the east coast of Scotland (Figure 4.1). Cropping in Scotland provides a useful example of a developed, intensive system which will be affected by climate related variables and has, in the past, been significantly affected by political changes, specifically the Common Agricultural Policy reforms (Brown et al., 2008; Scottish Government 2008, 2009b). The area is one of the few places in Scotland that is conducive to supporting intensive cropping, thanks to a relatively flat terrain and fertile soil. Due in part to the lack of biophysical and geographic constraints, farmers within the catchment are responsive to policy changes and market signals. The combination of relatively similar site characteristics and the adaptive behaviour of farmers provide the ideal conditions for evaluating policy adoption and effectiveness.

Approximately 115 farmers manage the 132 km^2 catchment. The area comprises 65% cereals and other arable crops for food and fodder (i.e. roots, legumes) and 35% as grassland (JAC 2008). Principally this is a cropping catchment, with only 4% of the total area designated as permanent grass and rough grazing, indicating highly extensive use of livestock within the farming system. Hence, whilst there are mixed livestock farms, most of the activities are intensive cropping and, perhaps supplement for provision of inputs into these systems. Since 2003, the catchment has been designated as a Nitrate Vulnerable Zone (NVZ), which leads to management constraints on farm decisions and production behaviour. In addition, the catchment formed part of the Scottish Environment Protection Agency's Monitored Priority Catchment Project which aimed to establish monitored baselines against which the effectiveness of diffuse pollution mitigation measures could be assessed (Vinten et al., 2009). Thus, the management of the catchment to reduce pollutants and foster pro-environmental behaviour has been of interest to policy makers.

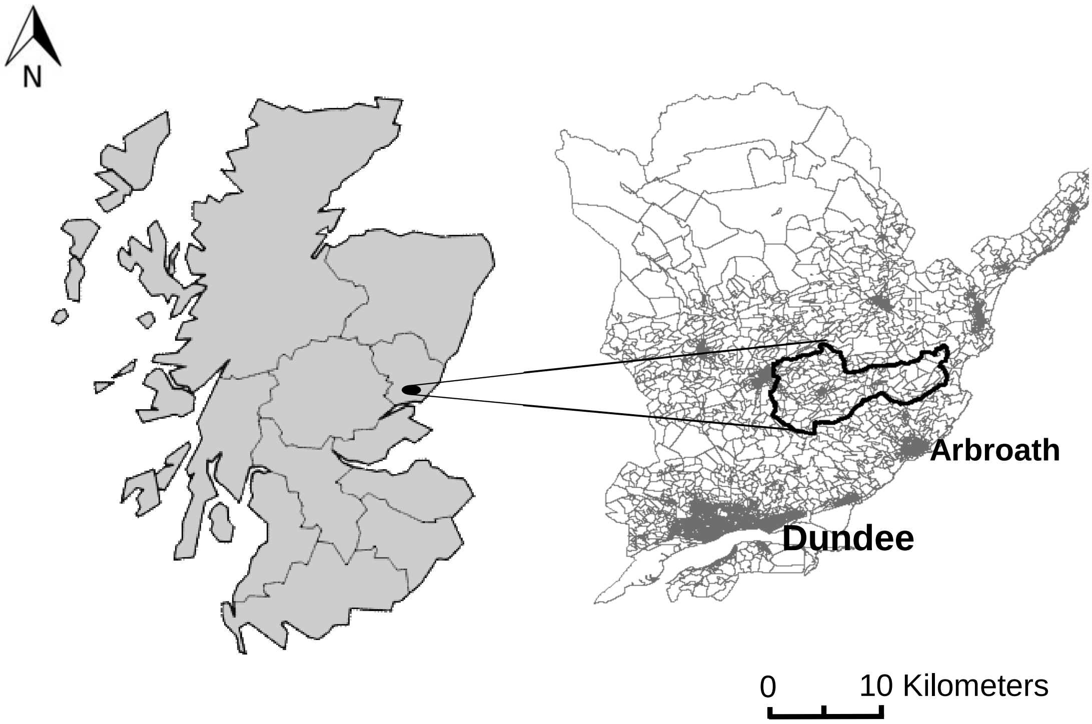

Figure 4.1 – Geographic location of the Lunan catchment in Scotland (Coordinates: -2.872029W, -2.522068E, 56.685096N, 56.578482S)

2.2 Description of the agent-based model

This paper describes an ABM that represents farmers' heterogeneous decisions towards alternative farm strategies in different socio-economic contexts (Figure 4.2). The conceptual framework models *farmer decision making* over a *landscape* composed of *farm*s, themselves containing a number *1…p* of *parcels*. The farmer agents choose a *farm strategy*, which is an aggregation of *regimes*, to apply to all the parcels within a farm. A regime is a multi-year plan composed of a number of *managements* applied to one parcel (i.e. a crop rotation). The regimes can be intensively or extensively produced, or be associated with *agri-environmental measures* (e.g. grass margins). We assumed that farmers *evaluate* a set of possible regimes in terms of their sustainable attributes (i.e. economic, social and environmental) and apply the regime with the highest utility to a parcel when the previous regime has ended. A *crop/Livestock model* returns the yield of each management at harvesting. This is used in association with the *socio-economic* *scenarios*, which give prices, subsidies and technological performance at a given time, to compute the economic value (i.e. income) of a given regime. These sub-models also serve at assessing the environmental and social attributes. Utility represents here the preference of an agent for a regime, and therefore the level of satisfaction that result from applying this regime. By enabling agents to choose amongst regimes, which may also differ in their temporal extent, the agent can plan for the future as well as make choices in the present (i.e. sacrifice today in order to obtain a better outcome in the future or maximise at present). This is possible by making choices at the level of a land-use regime (i.e. crop rotation or sequence of land covers and their associated managements) rather than the isolated choice of a single crop or land cover to be applied at an annual or subannual timespan (we refer to these as specific land managements).

The ABM was applied to the Lunan catchment for which GIS data were obtained (using the IACS data provided by the Scottish Government[10]). These data give information at the parcel level about farmer ID, geographic coordinates and a timeline of land uses from 2001 to 2008. The model was calibrated against these historical data, which also served to constrain the farmers in their choice of regimes by representing the limitation in skills and machinery for specific crops (i.e. potatoes, livestock, carrots).

The different components of the ABM are explained in details in the following sections: 1) the decision making model based on a utility function (described in Murray-Rust et al., 2011), 2) the empirical parameterisation of farmers in the Lunan catchment as computational agents, 3) the evaluation of regimes, and 4) modelling of biophysical entities (crop and livestock models). Finally three socio-economic scenarios are described.

[10] Integrated Administration and Control System. As part of this system used by the EU commission, farmers have the obligation to fill a form in order to obtain their direct payments and other subsidies.

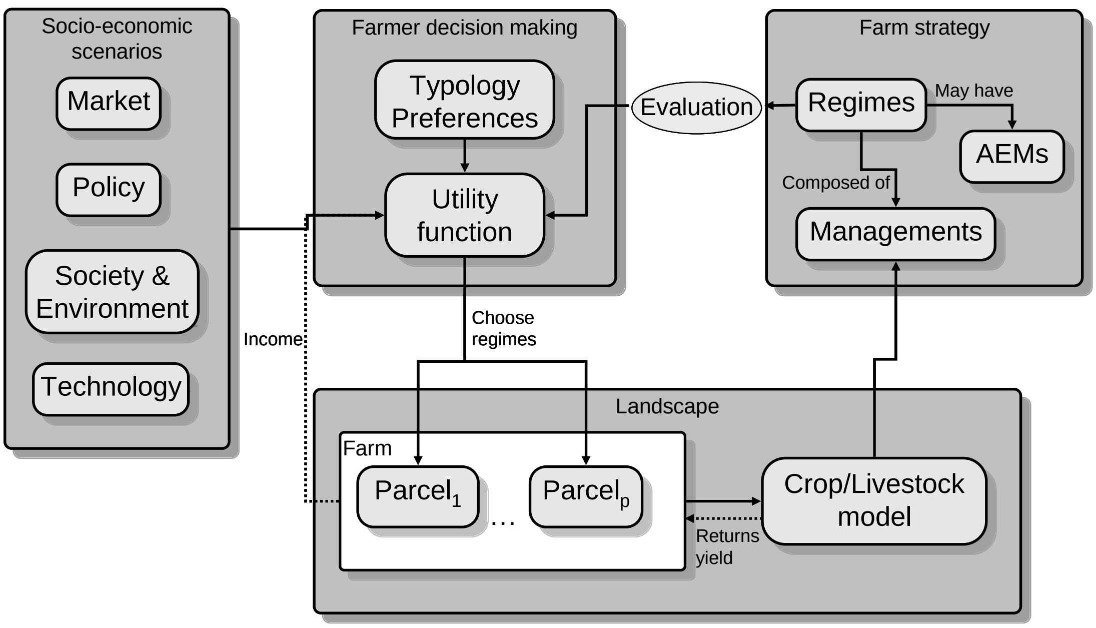

Figure 4.2 – Structure of the conceptual framework (Adapted from Murray-Rust et al., 2011).

2.2.1 Farmer decision making and empirical parameterisation of agents

The existence of multiple criteria, attributes and objectives is particularly important in decision making. The theory of multi-attribute utility has brought some insight into this process, upgrading the simulation of decision making to a more realistic level (Ghazali Mahayidin, 1982**;** Dyer et al., 1992). In neoclassical economic and rational choice theories, three assumptions are proposed. The decision maker makes rational choices between alternatives where [s]he balances "costs against benefits to arrive at action that maximizes personal advantage" (Friedman, 1953, p15). The decision maker also maximises utility and makes a choice independently and with access to complete information.

It was assumed that a farmer may choose a certain regime not only to increase profit, but also because they have knowledge of and concerns for its impact(s) on society and the environment. We used these criteria (or preferences), which represent the three pillars model of sustainability (Kastenhofer and Rammel, 2005), as the basis for selecting regimes by farmer agents using the following linear aggregate multi-attribute utility function:

$$U_j = U_{E_j} + U_{S_j} + U_{N_j} \tag{1}$$

, where U_j is the overall utility of a regime ***j***; U_{E_j}, U_{S_j}, U_{N_j} are the economic, social and environmental partial utilities respectively.

To represent heterogeneity in farmer decisions and to create a population of farmers, a typology was created based on the objectives and attitudes used by Lunan farmers to make land-management decisions. From random phone interviews applied to a selected sub-sample of farmers in the catchment, three attitudinal types were sufficiently homogenous to be represented by a replica of three software agents: Profit-oriented, Multifunctionalist, and Traditionalist (Table 4.1, see Chapter 3 for details[11]). These types are representative cases within the population and were used to scale-up respondent results to the agent population, which is a typical scaling-up approach (e.g. Brown and Robinson, 2006; Valbuena et al., 2008; 2010a,b). Because no significant differences were found between socio-economic and farm structure variables across types, the agents were proportionally and randomly distributed across the landscape and were attributed to real farm boundaries in the GIS datafile.

[11] Only the typology based on attitudes and objectives was used to parameterise the farmer agents in the model. The information on past census data analysis is not employed here.

Table 4.1 – Description of the attitudinal types and their frequency (Adapted from Chapter 3, section 3.2)

Profit-oriented (38%)	They maximise profit and do not hold strong positive attitudes towards the environment. Their intentions are to use the most profitable activities, but without innovating. They seek information in an individualistic manner (advisor, media…).
Multifunctionalist (25%)	They are oriented equally towards profit-maximisation, environmental and social objectives. They have strong values for the environment and participate in AES. Their activity is chosen for its profitability, but with respect for the environment by reducing chemical input. They intend to innovate if this fits with market and policy changes. They inform collectively (open days, other farmers…).
Traditionalist (36%)	Their main goal is lifestyle quality (environmental and social). They are reluctant to innovate and participate in AES but wish to reduce their impact on the environment by adapting their management. They have a local attachment and exchange information mainly with neighbouring farmers.

To evaluate quantitatively the non-use or passive-use aspects of a decision (e.g. social feedback, impact on the environment) as well as the economic aspects of decision-making typically used within economic theories (Alriksson and Oberg, 2008), a Choice-Based Conjoint (CBC) approach was implemented (Adamowicz et al., 1995). CBC analysis is a technique used to derive the importance and partial utilities of different levels of one attribute of interest relative to others by a survey respondent.

In the conjoint experiment, respondents, who were assigned an attitudinal type in the phone survey phase and who accepted to participate in the experiment, were presented with several choice tasks whereby they are asked to choose one land use option in each task. Each option was described by a combination of levels of attributes (Table 4.2; Appendix D). The decompositional nature of CBC is appropriate for the prediction of decision behaviour, especially with a priori segmentation, i.e. attitudinal types (Montgomery and Wittink, 1980; Sattler and Hensel-Borner, 2003; Alriksson and Oberg, 2008).

Table 4.2 - Attributes and their levels used for constructing choice tasks

Attributes	**Levels**
Farm activity	Crop; Livestock; Non-Food; Manage Environment
Social Feedback	Positive; None; Negative
Environment Impact	Degrade; Maintain; Enhance
Change in income	Low (-10%); Unchanged; High (+10%)

The responses were analysed using a Hierarchical bayes Choice-Based Conjoint (HCBC) model to capture preferences of individual respondents as well as groups of individuals, i.e. segment level (Orme and Howell, 2009). Only 10 respondents in total returned a completed questionnaire (4 profit-oriented farmers, 3 multifunctionalists and 3 traditionalists). However, Hierarchical bayes analysis creates the opportunity to recover both the individual-level and the heterogeneity in partial utilities, even when the number of responses per respondent is less than the number of parameters per respondent (Lenk et al., 1996). This makes the model in equations (2) and (3) very useful in cases of small respondent samples.

$$Y_i = X_i.\beta_i + \varepsilon_i \tag{2}$$

$$\beta_i = \Theta.z_i + \delta_i \tag{3}$$

, where $\boldsymbol{i}$ = 1 ….n number of respondents, $\boldsymbol{Y_i}$ is a vector of the responses from the choice tasks, $\boldsymbol{X_i}$ is a matrix of the attribute levels, and $\boldsymbol{\beta_i}$ is the $\boldsymbol{p}$-dimensional vector of regression coefficients representing the part-worths, ε_i is a $\boldsymbol{p}$-dimensional vector of random error terms. The individual-level model represented by Equation (2) assumes that the respondent chooses options according to the sums of partial utilities as specified in logit models. In equation (3), Θ is a $\boldsymbol{p}$ by $\boldsymbol{q}$ matrix of regression coefficients, $\boldsymbol{z_i}$ is a $\boldsymbol{q}$-dimensional vector of covariates and δ_i is a $\boldsymbol{p}$-dimensional vector of random error terms.

The upper-level model (Equation 3) describes the heterogeneity in the individual partial utilities across the population of respondents. The heterogeneity is captured in covariates, i.e. the attitudinal types, describing the respondent attributes. According to Orme and Howell (2009), the most useful covariates bring exogenous information (outside of the information already available in the choice tasks) to the model to improve the estimates of partial utilities.

Figure 4.3 shows the average non-linear response that respondents of a given attitudinal type have towards attribute levels[12] (see also Appendix E). The consideration of levels of attribute instead of attribute importance in the calculation of the overall utility brings stronger explanatory power to the decision making framework since it includes more information. Indeed, it contributes to our understanding of how the variation in an attribute level alters the overall utility and explains the choice of an option (Menichetti, 2010). For instance, profit-oriented farmers, although holding strong preference for the attribute environment, would rather choose to maintain the environment over enhancing it.

A set of indicators were used to represent the economic (E), environmental (N) and social (S) values that farmers use when evaluating each regime $\boldsymbol{j}$. The calculation of indicator values is explained in the following section.

[12] The partial utilities have been normalized to zero-centred differentials to impose equal weight of each respondent in the segment average. Across attributes, the partial utilities have arbitrary scaling with respect to one another.

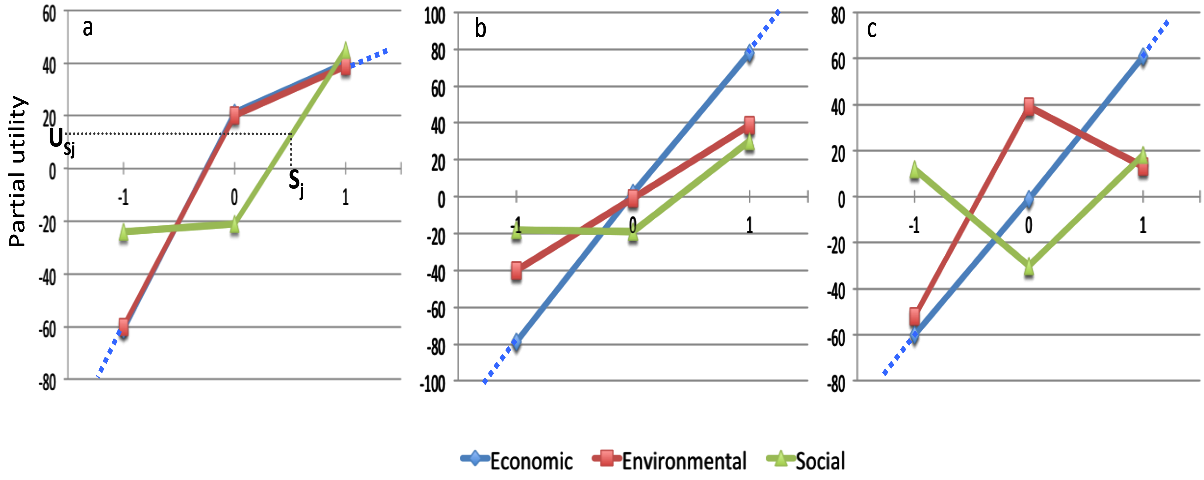

Figure 4.3 – Average non-linear partial utilities functions associated to a: Traditional farmers, b: Multifunctionalist farmers, and c: Profit-oriented farmers. As an example, S_i is the social score attributed to a given regime j. The respective partial utility of the social attribute Us_i is function of S_i. The x-axis units -1; 0; 1 correspond to: -10%; 0; +10% profit for the calculation of the economic score E; degrade; maintain; enhance for the environmental evaluation (N); negative; neutral; positive social feedbacks for the social evaluation (S)

2.2.2 Evaluation of regimes

A list of all possible regimes for the arable areas of Scotland was collected[13]. There is in total 163 different regimes, 70 are intensive, 65 extensive, 21 regimes with agri-environmental measures (19 intensive regimes with 1% of the area planted as grass margin and 2 voluntary set-asides), and 2 bio-energy regimes (Willow and Miscanthus).

The regimes' performance across economic, environmental and social factors was assessed through a scoring system that corresponds with the attribute levels used in the CBC survey. Scores are difficult to estimate since they are a function of a farmer's (incomplete) knowledge. A set of indicators was selected using literature

[13] (Steven Thomson, SAC Agricultural Economist, pers. Comm.).

and focus groups among scientists[14] studying rural and farm land systems. The indicators were designed conceptually to represent factors thought to influence a farmer's evaluation and choice of farm strategies. Besides which, the environmental aspect is particularly ambiguous since the effort made towards environmental conservation is generally of "serependic" or "utilitarian" values rather than direct (Swift et al., 2004). In this paper, we designed a scoring system that is hypothetically understood by farmers and is relatively easy to process.

Economic score E. The economic indicator *E* was represented by the expected economic contribution of a given regime on a hectare basis. This contribution was expressed as the difference existing between the farmer's average gross margin over the past 5 years and the expected gross margin estimated for a new regime ***j***. Gross margins were calculated with yearly data on: average prices and yields, costs (including labour, seed, fertiliser, pesticide, machinery) and subsidies attached to a management ***i*** (FMH[15] and Economic Reports on Scottish Agriculture[16], various years). The economic score was the only one to be unbounded since it represents a unit of + or – 10% in gross margins (see Table 4.2). This implies more weight to the economic aspect of decision.
The calculation of this indicator is explained by Equations 4 to 7. The calculation of the gross margin of regime ***j*** of length ***t***, $\boldsymbol{GM_j}$, was calculated following Equation 4. The 5-years average gross margin of the farm is demonstrated in Equation 5 and 6.

$$GM_j = \frac{\sum_1^i (Y_i \cdot P_i - C_i + Sub_i)}{t_j} \tag{4}$$

where $\mathbf{P}_i$ is the price of management ***i*** (£/tonne), $\mathbf{Y}_i$ is the average yield of ***i*** (tonne/Ha), and $\mathbf{Sub}_i$ is the subsidy associated to management ***i*** (£/Ha). The variable costs associated to a management $\mathbf{C}_i$ (in £/Ha) include seed, fertiliser, pesticide,

[14] Three focus groups with partners collaborating on the European project Ecochange occurred between 2008 and 2010. Among the participants were biologists, economists, and sociologists.
[15] Farm Management Handbook is edited by SAC and provides a variety of information on the UK arable and livestock sector (e.g. detailed gross margins calculation).
[16] The Economic Reports on Scottish Agriculture are published annually by the Scottish Government since 1999. The reports compile "Farm Accounts results, Total Income From Farming estimates and Agricultural Census statistics". They are available via open access: http://www.scotland.gov.uk/Topics/Statistics/Browse/Agriculture-Fisheries/PubEconomicReport

labour (labour requirement units multiplied by the average standard salary for Scotland), machinery (contract work and machinery maintenance (FAD)) and other costs (baling, British Potato Council levy, boxes…).

To estimate the 5-years average gross margin of a farm, $\overline{AGM}^{*}$, we first calculated the farm gross margin at time ***t*** , $\overline{AGM}_t$ (Equation 5), and the average gross margin over the period ***t*** to ***t+5*** (Equation 6) per hectare, ***A*** being the hectare area and ***n*** is the parcel[17]:

$$\overline{AGM}_t = \frac{\sum_1^n (GM_j \cdot A_n)}{\sum_1^n A} \tag{5}$$

$$\overline{AGM}^{*} = \frac{\sum_{t=1}^{5} \overline{AGM}_t}{5} \tag{6}$$

The relative contribution of regime ***j*** (Equation 7) was scaled such that an increase of 10% relative to the current average gross margin gets a score of 1; this brings it in line with the attribute levels used in the choice experiment survey. The utility UE_j was then function of the percent change in gross margin (the unit being 10%) (Guillem et al., 2011; Robinson et al., 2011).

$$E_j = \frac{GM_j - \overline{AGM}^{*}}{\overline{AGM}^{*}} \times 10 \tag{7}$$

Environmental score N. The score *N* was characterised by three indicators: crop cover, nitrogen need and diversity. The first two indicators are adapted from a European Concerted Action on Integrated Farming project (Vereijken, 1999) and are applied at the management level. The notation system used for these indicators was formerly designed by DEFRA (2002) for farmers to easily estimate target scores to switch from conventional to integrated farming management.

[17] Five years is the average rotation length found in intensive arable areas.

The crop cover scoring system considers the coverage of a parcel depending on the management's timing of activities over one year (Table 4.3). The length of coverage is important to limit soil erosion (Pierce et al., 1986; Langdale et al., 1991) and leaching of nutrients or harmful chemicals (Shepherd and Lord, 1996; Francis et al., 1998). The score of regime ***j*** for cover is calculated with Equation 8, with $\boldsymbol{t_j}$ the length of regime ***j*** (number of years).

$$Cover_j = \frac{\sum Cover_i}{t_j} \tag{8}$$

Nitrogen need is the difference between the relative amount of nitrogen a given management ***i*** extracts from the soil nutrient content (*Nofftake*) and the amount it transfers back to the soil after harvest (*Ntransfer*) (Vos and van der Putten, 2000) (Table 4.3). This depends strongly on the plant group and management style (e.g. spring versus winter sown, intensive versus extensive). These scores do not take into account biophysical variability (e.g. slope, soil texture). Equation 9 was used to calculate the nitrogen need score $Nneed_j$ of a regime *j*.

$$Nneed_j = \frac{\sum[(Nofftake_i - |Ntransfer_i|) \div 2]}{t_j} \tag{9}$$

Table 4.3 – Scores attributed to all management considered in the model for cover, nitrogen offtake and transfer (Adapted from DEFRA, 2002)

Crop type	Plant group	Cover[b]	N offtake[c]	N transfer[d]
Winter wheat extensive and intensive	W Cereal	1	-1	-1
Spring wheat extensive and intensive	S Cereal	-0.5	-0.5	-1
Winter barley intensive	W Cereal	1	-1	-1
Winter barley extensive	W Cereal	1	-0.5	-1
Spring barley/oat intensive	S Cereal	-0.5	-0.5	-1
Spring barley/oat extensive	S Cereal	-0.5	0	-1
Winter oat extensive	W Cereal	1	-0.5	-1
Winter oilseed rape extensive and intensive	Brassicas	1	-1	0
Spring oilseed rape intensive, OSR for stockfeed	Brassicas	-1	-0.5	-1
Spring oilseed rape extensive, Industrial OSR	Brassicas	-1	0	-1
Winter beans	Legumes	-0.5	1	0
Spring beans, Spring peas	Legumes	-1	1	0
Ware Potatoes, Turnips	Solanales	-1	-1	0
Seed potatoes, Swedes	Solanales	-1	-0.5	0
Carrot, Turnips for stockfeed	Apiales	-1	0.5	-1
Grass under 5 years old, Intensive Grazing	Poaceae	1	-1	0
Extensive Grazing	Poaceae	1	-0.5	0
Fallow, Rough Grazing	Poaceae	1	1	0
Set-aside	Other	1	0.5	-1
Maize	Poaceae	-1	-0.5	0
Willow	Salicaceae	1	0.5	0
Miscanthus	Poaceae	1	1	0

[b] **Cover score**: -1: no cover in autumn and winter; -0.5: no cover in autumn; 0: crop sown in late autumn; 0.5: crop sown mid-autumn; 1: crop sown early autumn.

[c] **Nitrogen offtake** (N offtake): -1: 150-200 Kg/Ha of nitrogen taken from soil reserve; -0.5: 100-150 Kg/Ha; 0: 50-100 Kg/Ha; 0.5: 25-50 Kg/Ha; 1: <25 Kg/Ha.

[d] **Nitrogen transfer** (N transfer): -1: <50 Kg/Ha of nitrogen returned to the soil and available for the following crop; 0: 50-100 Kg/Ha; 1: 100-150 Kg/Ha ([c] and [d]: Vereijken, 1997).

The third N indicator, diversity, was applied at the regime level and was computed using a simple set of rules. Two aspects of rotation diversity were assessed: temporal diversity which is the length of a crop rotation (in years) and biodiversity which is the composition of the rotation in term of plant groups. Longer rotations typically increase diversity in insect species (Clergue et al., 2005) and reduce the risk of crop failure due to a single pest outbreak (Altieri, 1989).

Assuming monoculture represents the least preferable level of diversity, a minimum score of -1 was attributed to it. Each additional crop type increases the score by a value of 0.25 until a maximum is reached of 8 managements (score = 1), which is the maximum length of a regime generally found in Scotland[3]. Bioenergy regimes, e.g. miscanthus and willow, respectively 18 and 15 years and non-rotational set-aside were considered as monoculture.

A rotation being more biodiverse leads to the structuration and aeration of the soil, e.g. different root systems (Eastern Canada Soil and Water Conservation Centre, 1993).

The same scoring system was attributed to each plant group found in the rotation. The lowest score, -1, is given when only one plant group is found in the rotation and the score is increased by unit of 0.5 for each additional plant group (maximum 5 plant groups). For instance, a 4-years rotation composed of spring barley, spring wheat, peas and winter oilseed rape will have a score of 0 for the temporal diversity and a score of -0.25 for the diversity in plant groups. Then [0 + (-0.25)]/2 = -0.125 is the final score for the diversity of this regime.

The overall environmental score N (Equation 10) is composed of a cover score (Equation 8), nitrogen need score (Equation 9) and a diversity score[18]:

[18] For regimes with grass margins, the environmental and social indicator scores were computed at the regime level. Since 1% of a parcel is planted with permanent grass strip, the cover score is increased by (0.1*1)/ $\mathbf{t}_j$, the score for diversity is increased by ((0.25*0.1)+(0.5*0.1))/ $\mathbf{t}_j$. The value for Nitrogen need is not affected by the presence of grass margins.

$$N_j = \frac{Cover_j + Nneed_j + Diversity_j}{3} \tag{10}$$

Social score S. Several methods have been used to assess the recreational and aesthetic value of a spatial arrangement of crops. For instance the number of visitors it attracts (Fleischer and Tsur, 2000), the combination of a set of elements contained in the landscape (Arriaza et al., 2004; Hall, 2010), the preferences attributed to the general visual effect of a landscape (Lindemann-Matthies et al., 2010). In our case the assessment of social values was done at the parcel level with a temporal scope (i.e. regime), thus we combined these different landscape scale approaches to the parcel scale.

We identify two components of social consideration that may be appropriately applied at a parcel level. The social score ***Sj*** is calculated by the average of scores for access to green space ***G*** and for tradition ***T*** of a management ***i***. Thus the social score of a regime ***j*** is calculated through Equation 11:

$$S_j = \frac{\sum (G_i + T_i)}{t_j} \tag{11}$$

The access to green space indicator ***Gi*** assesses the suitability of a management ***i*** for recreational activities, i.e. walking, horseback riding, cycling, bird watching. This assessment is done qualitatively:

- a value of -1 was given to restricted access (e.g. Fruit, Willow, Miscanthus, Sunflowers, Abandoned),
- a value of 0 is given to limited access, i.e. after crop harvest, when livestock is not present, during snow cover (e.g. arable crops and grassland), and
- a value of +1 is attributed to easy access (e.g. forest, crops associated with grass margins, Set-asides).

The traditional aspect is determined as a function of years where a management has occurred in the area. The use of information on output production from 1992 has permitted this determination (Economic Report on Scottish Agriculture, various years). The scores attributed to a management remains fixed across simulations.

2.2.3 Landscape entities

Crop model. A basic vegetation model is applied to all managements, which does not implement physical response to climate. It is configured using growth curves that represent the average harvestable biomass of a crop throughout a given year based on historical data. A technological coefficient is applied to the 2002 average yield of a given management for each subsequent year (Abildtrup et al., 2006). These coefficients are scenario-specific (see following section). Farm management actions are limited to fixed sowing and harvesting. The dates of actions are taken from the literature available for Scotland (SAC, various years).

Livestock model. We assumed that farmers with grassland over 5 years old and rough grazing are producing beef. In the lowlands most beef farmers rear cattle from birth to “finish”, i.e. at 3 years old, therefore the time between start and harvest was set to 3 years. The livestock model converts the crop yield (plant biomass) ***Yi*** of a given parcel ***p*** (of area ***A***) into meat output ***B*** (in ton) using a basic equation (Equation 12). The ***EnergytoMass*** is a constant that represents the energy needed to grow 1 ton of saleable meat. Using the equation from Smeaton[19] (2007), the consumption requirement to sustain the development of an adult of 560 Kg (average target weight of Angus and Charlais; Barber, 1981) was estimated at 37265 Mega Joules (MJ). The carcass weight represents 60% of the live weight (FAO, 1991) and only 70% of the carcass weight is saleable (FMH, 2010). Therefore 170940 MJ is needed to produce 1 ton of saleable meat[20]. ***harvestEnergy*** is the amount of energy available to cattle from the digestion of 1 ton of grass (3010 MJ; NAS, 1971).

$$B_{i,p} = \frac{Y_i \cdot A_p}{EnergytoMass / harvestEnergy} \tag{12}$$

[19] Smeaton’s Equation estimates the required metabolizable energy in MJ/day. To calculate the energy demand for growing a cow, a daily weight gain of 1.57Kg was applied (Cundiff et al., 1993).

[20] 37265 MJ is needed for growing 0.560t of live cattle (LW). During processing, the initial mass is reduced: 0.560 (LW) * 0.6 (Caracass weight) * 0.7 (Saleable meat) = 0.218 ton of saleable meat. So for 1 ton of saleable meat, 37265/0.218 MJ is necessary (=170940 MJ).

2.3 Socio-economic scenarios

The ALARM (Assessing Large-scale Risks for biodiversity with tested Methods) scenarios have been developed as part of the EU 6th Framework Programme for sustainable development, global change and ecosystems (Bohunovsky et al., 2011; Settele et al., 2012; Spangenberg et al., 2012). Three of the ALARM-based socio-economic scenarios were adapted to the case study to analyse the effects of exogenous factors on the endogenous decision making process:

- BAMBU (Business-As-Might-Be-Usual) represents approximately the current regional trends and can therefore be considered as a baseline for comparison to other scenarios. Within the context of BAMBU, land policies are oriented towards the improvement of the standard of living, particularly the viability of farm businesses as a source of income and the maintenance of a healthy environment. Commodity prices are generally stable while input costs increase slightly over time. Throughout the scenario direct payments decrease slowly while agri-environmental subsidies increase at a similar rate. This shift represents the possible post-2013 CAP reform which plans on transferring funding from Pillar I to Pillar II (Dwyer, 2011). The average yields per hectare are doubled. No financial reward is proposed for the production of renewable bio-products putting more emphasis on food production.
- GRAS (GRowth Applied Strategy) is characterised by economic liberalism, free trade and international competitiveness. Support and agri-environmental payments vanish and the demand for food of high quality decreases, encouraging farmers to intensively produce high yielding commodities. The output prices are significantly decreasing towards 2050 while labour cost increase sharply. However chemical inputs (i.e. fertilisers and pesticides) prices decrease but technological performance permits to return very high yields (yields triple by 2050). This situation accentuates individual responsibility towards environmental and social issues and implies the need for diminishing costs of production (predominance of monocultures).
- In SEDG (Sustainable European Development Goal), policies are oriented towards multifunctionality and local needs. Output and input prices increase while the performance of yields increases very slowly. High prices for energy, the possibility for local production of energy and policy incentives suggest an increasing viability of bioenergy cropping. Subsidies to support

farm income progressively reach zero towards 2050 but payments for agri-environmental measures (i.e. grass margin and set-aside) increases.

Market trends and changes to subsidy levels were taken from the EU-15 agricultural model parameters estimates for 2020 and 2050 (Abildtrup et al., 2006). The three Special Report on Emission Scenarios (SRES, Nakicenovic et al., 2000), World Market (A1F1), Regional Enterprise (A2) and Local Sustainability (B2) correspond to the ALARM storylines GRAS, BAMBU and SEDG respectively (Millenium Ecosystem Assessment, unpublished).

3. Simulation results

3.1 Model verification

To assess the plausibility of the model performance, a number of verification experiments were performed. At each step of the model development a series of "unit tests" were carried out to search for errors in the code (Beck, 2002). These unit tests are independent pieces of code that relate to a single equation in the software. Hence, it is possible to compare model outputs with expected results. The verification process is extended to integration testing when all the units are combined. One of the integration experiments was verifying the selection of regimes by farmers through the optimisation of the utility function (Equation 1). We applied one attribute at a time (i.e. economic or environmental or social), removed the constraints (i.e. tags), and set constant variables (market, technology, subsidies).

When the overall utility of a regime is equal to the social utility (the other partial utilities, economic and environmental (U_E, U_N), are set to 0), all farmer types selected regimes with grass margins for which the social score is the highest. Similarly, farmer assessment of a regime based exclusively on the environmental partial utility (when $U_E, U_S = 0$) has shown a preference for regimes with a highest environmental score in multifunctionalist and traditional farmers (i.e. set-aside) and for extensive regimes that have an environmental score close to zero for profit-oriented farmers. Indeed, profit-oriented farmers have a nonlinear response to the environmental attribute levels (see Figure 4.2). Finally, when farmers evaluate regimes solely on economic factors (when $U_S, U_N = 0$), they chose regimes with the highest profit.

3.2 Simulation outputs

Farm strategies (i.e. land uses, management style, agri-environment measures) are given for the three types of farmers in each scenario, as a proportion allocated to farmland for the years 2025 and 2050. In addition, the resulting average subsidy to income ratio for the period 2008 to 2050 is given.

To understand further why different farmers make different choices, the average scores of environmental and social indicators were recorded. These scores represent the expected environmental impacts and social feedbacks from the regimes that farmers choose. The resulting utility (and partial utilities) is then derived from these choices. Assuming farmers choose the best regime (i.e. with highest total utility), the overall utility averaged for a specific farmer type shows how different types of farmers are satisfied with regard to different socio-economic scenarios. Between 2001 and 2007, the regimes from historical data were used for calibration and, as such, are not allocated scores.

3.2.1 Farm strategies and land use change

In general, the allocation of land uses to the farm only differs slightly between farmer agent types and this is more evident when comparing across scenarios (Figure 4.4, Table 4.4). Multifunctionalists apply a variety of land uses, in particular innovative bioenergy crops, spring cereals and legumes. The traditionalists and profit-oriented farmers seem to maintain cereal-based regimes. In particular, the traditionalists tend to apply in general the same land uses, i.e. cereals, whatever the socio-economic context. Profit-oriented farmers however switch to other land uses, but at a more incremental pace than the multifunctionalist.

In BAMBU, the land use remains relatively unchanged from 2025 to 2050 for all farmer types. Both traditionalists and profit-oriented farmers increase slightly the land allocated to winter cereals to the detriment of spring cereals. In contrast, the proportion of land planted with spring-sown cereal in 2025 and 2050 is significantly higher for multifunctionalists.

Outputs from the GRAS scenario show a bigger change both in terms of temporal evolution and in the diversity of land uses. The socio-economic climate in this scenario seems to cause farmers to diversify land use. In 2025, the three types of farmers grow cereals on more than 90% of their land, although multifunctionalists and profit-oriented farmers have some legumes and miscanthus. By 2050, the land uses are the most diverse (compared to the other scenarios) and this is the case for all farmer types. However the multifunctionalists allocate other land uses such as roots, legumes and miscanthus to more land than the two other groups which keep about 70% of their land for cereals (compared with 60% for multifunctionalist).

In SEDG most farmers essentially grow cereals in 2025, but by 2050 the multifunctionalists have switched from cereals (significantly more spring-sown) to the bioenergy crop miscanthus on more than 45% of their land. Traditionalist and profit-oriented farmers also adopt miscanthus, but on a smaller area of their farms, respectively 12 and 26%.

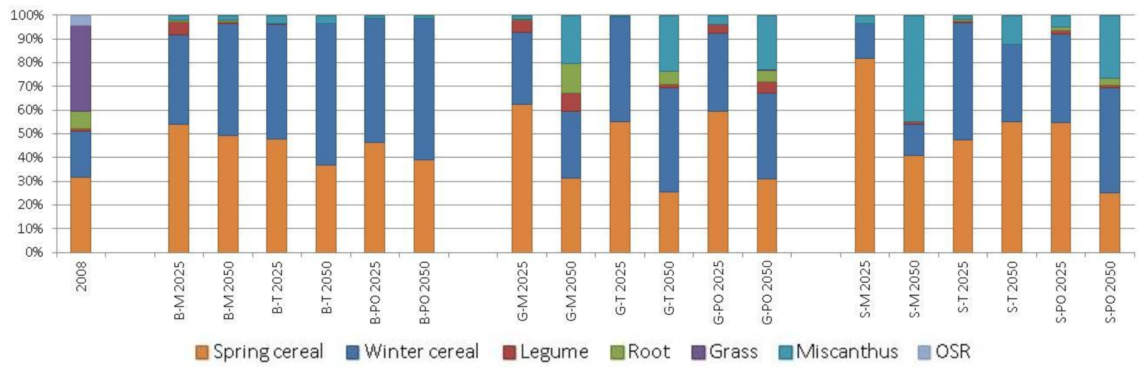

Figure 4.4 – Proportion of land uses in 2025 and 2050 for each scenario and each farmer type (B: BAMBU, G: GRAS, S: SEDG and M: Multifunctionalist farmers, T: Traditional farmers, PO: Profit-oriented farmers).

Table 4.4 – Average proportion of land use types (%). M: Multifunctionalists, T: Traditionalists, PO: Profit-oriented

	2008	2025			2050		
		M	T	PO	M	T	PO
BAMBU							
Spring cereal	31.74	54.07	47.91	46.40	49.46	36.95	39.02
Winter cereal	19.33	37.62	48.15	52.19	47.05	59.43	59.56
Legumes	0.85	5.61	0.45	0	0.61	0.09	0
Root	7.38	0.72	0	0	0.77	0	0
Grass	35.85	0	0	0	0	0	0
Miscanthus	0	1.98	3.50	1.40	2.11	3.52	1.42
OSR	4.33	0	0	0	0	0	0
GRAS							
Spring cereal	31.74	62.66	55.35	59.74	31.25	25.66	31.01
Winter cereal	19.33	30.26	44.01	32.77	28.20	43.71	36.27
Legumes	0.85	5.02	0.28	3.79	7.77	1.63	4.59
Root	7.38	0.48	0	0	12.30	5.22	4.72
Grass	35.85	0	0	0	0	0.24	0.64
Miscanthus	0	1.56	0.37	3.71	20.48	23.53	22.77
OSR	4.33	0	0	0	0	0	0
SEDG							
Spring cereal	31.74	78.35	47.80	53.84	41.03	55.18	25.10
Winter cereal	19.33	13.79	49.69	36.58	13.18	32.49	44.50
Legumes	0.85	0	0.69	1.44	0.96	0	1.12
Root	7.38	0	0.69	1.44	0	0	2.74
Grass	35.85	0	0	0	0	0	0
Miscanthus	0	3.42	1.67	4.77	44.82	12.33	26.53
OSR	4.33	0	0	0	0	0	0

The management styles differ between farmer types and across socio-economic scenarios (Figure 4.5). The land is managed intensively and the multifunctionalists apply agri-environmental measures and bioenergy on a larger area than the two other types. In BAMBU, while both profit-oriented and traditionalist farmers maintain a small number of regimes with grass margins across time, the multifunctionalists increase them. In addition, the profit-oriented farmers are the only type to apply a small area of extensive regimes. The proportion of management styles is very similar between farmer types in the GRAS scenario: a small area of regimes with grass margins is replaced by bioenergy by 2050. The biggest difference between farmer types is found in the SEDG outputs. In 2025, the multifunctionalists apply more than 25% of their land to regimes including grass margins and about 10% of extensive regimes, the rest being intensive; in 2050 however this is replaced by bioenergy crops. Only 18% of the land is managed extensively by the traditionalists or associated with agri-environmental measures. The traditionalists increase intensive management further by 2050 with a small area being allocated to bioenergy (about 10%). The profit-oriented farmers reduce regimes with intensive management by more than 35% in 2025, as do the multifunctionalists, but they prefer extensive management rather than agri-environmental measures. In spite of this, by 2050, this management becomes more intensive and 20% of the land is allocated to bioenergy crops.

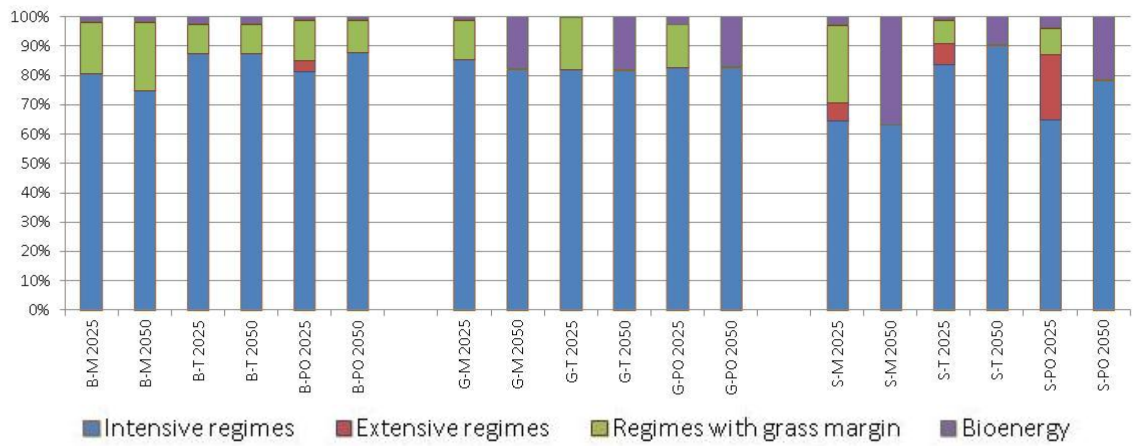

Figure 4.5 - Proportion of management styles in 2025 and 2050 for each scenario and each farmer type (B: BAMBU, G: GRAS, S: SEDG and M: Multifunctionalist farmers, T: Traditional farmers, PO: Profit-oriented farmers)

3.2.2 Subsidies

The benefit of the direct payments to total income is significantly higher in BAMBU, where the payments are relatively stable until 2050. However, no significant differences were found between farmer types (Figure 4.6 a.).

Significant variations are shown in Figure 4.6 b. for other types of subsidies (e.g. Pillar 2 agri-environment payments). In particular, in the BAMBU and SEDG scenarios where the profit-oriented farmers made the most profit out of these subsidies compared with multifunctionalists and traditionalists. Almost 2% of profit-oriented farmers income comes on average from grass margins and voluntary set-aside in BAMBU, while only 0.7% contributes to income in SEDG (with an additional 1.5% from support for bioenergy). In the GRAS scenario, the relative contribution of subsidies from Pillar II is less than 1% for all farmer types. However the profit-oriented farmers obtained better returns from grass margins than from voluntary set-aside.

The percentage of Pillar II-types of subsidies is relatively stable across scenarios for the multifunctionalists. The application of voluntary set-aside provides more income than grass margins, especially in GRAS and SEDG, although they allocate a reasonable area of regimes with grass margins on their land.

The traditionalists do not take full advantage of agri-environment subsidies in BAMBU (only 0.5% of total income). Nevertheless this percentage increased in SEDG (almost 1.5%), balancing the financial benefits of grass margins, set-aside and bioenergy crops.

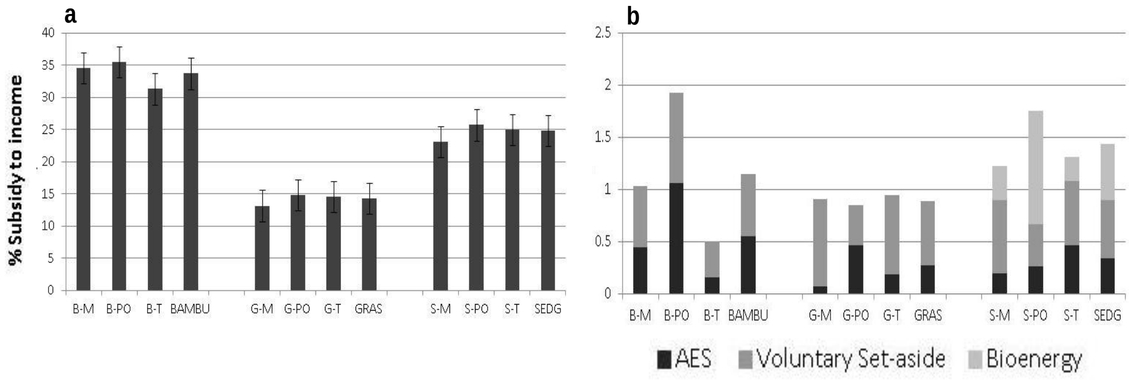

Figure 4.6 – Percentage of subsidies received over the period 2008-2050 to total income, a: Direct payments (includes cereals, cattle premium, protein and oilseed rape crops) and b: Other subsidies such as Agri-environmental (for grass margins option), voluntary set-asides and Bioenergy. (B: BAMBU, G: GRAS, S: SEDG and M: Multifunctionalist farmers, T: Traditional farmers, PO: Profit-oriented farmers)

3.3 Valuation of environmental and social indicators, and overall utility

Generally, the environmental score is negative in all scenarios and for all farmer types (Figure 4.7). This is due mainly to the poor scores attributed to nitrogen need for the regimes considered in the model.

In BAMBU and GRAS, the multifunctionalists selected, on average, the regimes with the lowest environmental score (cover and diversity) in contrast to the other two types. The low cover score is due to their preference for spring-sown cereals in BAMBU and this increases in GRAS with the application of more bioenergy crops. The diversity in BAMBU shows that multifunctionalists choose shorter regimes than the other farmer types. In GRAS there are less apparent differences in the diversity scores between farmer types, and these scores decrease from 2030. However the diversity in plant group that compose selected regimes has been shown to be higher in 2050 (see Figure 4.4) meaning that it is the temporal diversity which is significantly reduced.

In SEDG, each farmer type demonstrates higher value for one indicator in particular: profit-oriented farmers value the cover aspect (more winter-sown crops), the traditionalist farmers choose more diverse regimes, and the multifunctionalists increase regimes that demand less nitrogen (i.e. bioenergy). The total environmental score in this scenario is relatively similar between farmer types, although profit-oriented farmers and multifunctionalists had a higher more stable score than traditionalists for whom the score slowly decreases.

The total social value is similar between farmer types in BAMBU and GRAS, while significant differences are found in SEDG (Figure 4.8).

In BAMBU, the total social score is the highest and remains stable from 2020. Although the total score or the score for the element “tradition” is relatively similar across types, access to green space differs from 2028. Multifunctionalist farmers selected more regimes with high access values (through the implementation of grass margins) than traditionalists and profit-oriented farmers, and thus maximised the social aspect over the environmental issues.

The importance of the social indicators decreases from 2030 in the GRAS scenario for all farmer types. However, these values diminish more rapidly and abruptly for the profit-oriented farmers.
In SEDG, the changes in social feedback values appear around 2020. The traditionalist farmers demonstrated preferences for this aspect in their decision for both access to green space and level of tradition. This corresponds with the observation of lower environmental scores attributed to the chosen regimes. The multifunctionalists have the lowest score, which is due to the switch of almost 40% of their land area to bioenergy crops, which have a very poor social value, although the environmental attribute is simultaneously enhanced.

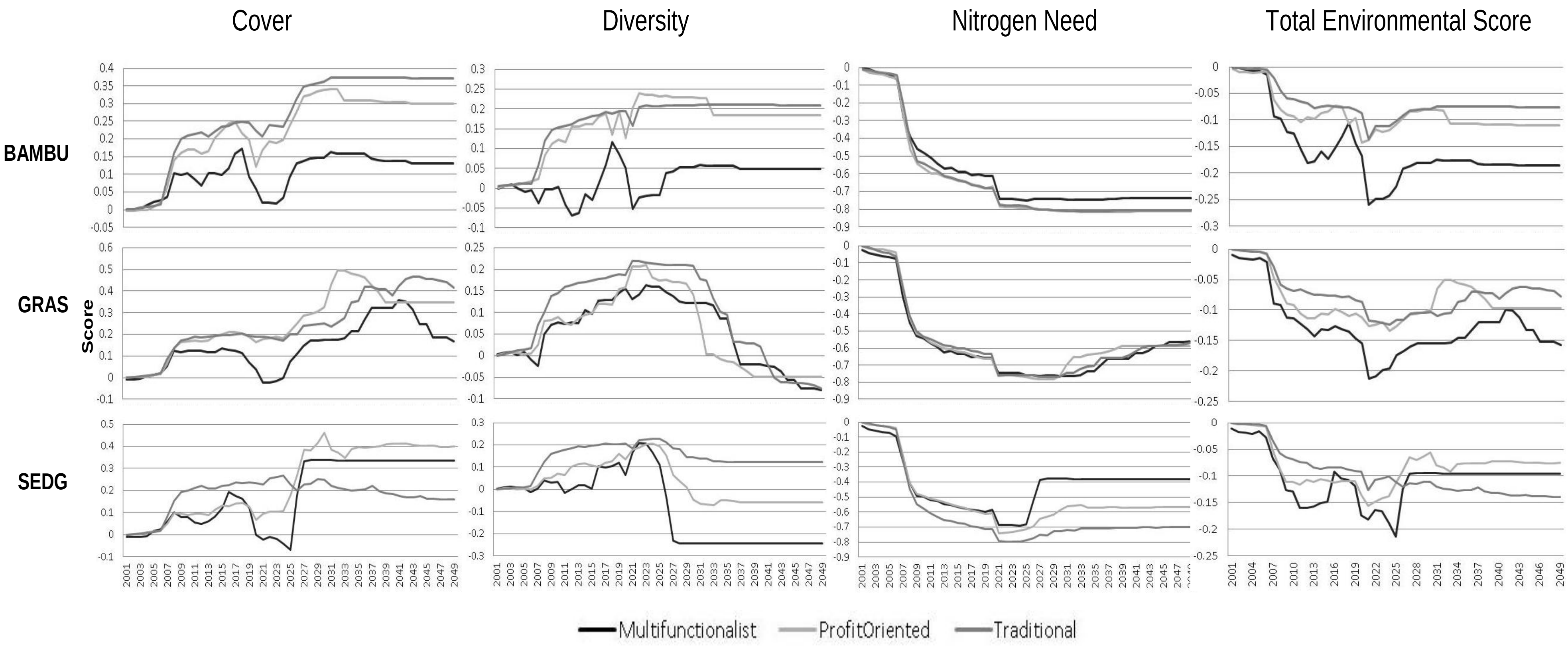

Figure 4.7 – Environmental indicator scores across time for Multifunctionalist, Profit-oriented and Traditional farmers in each scenario

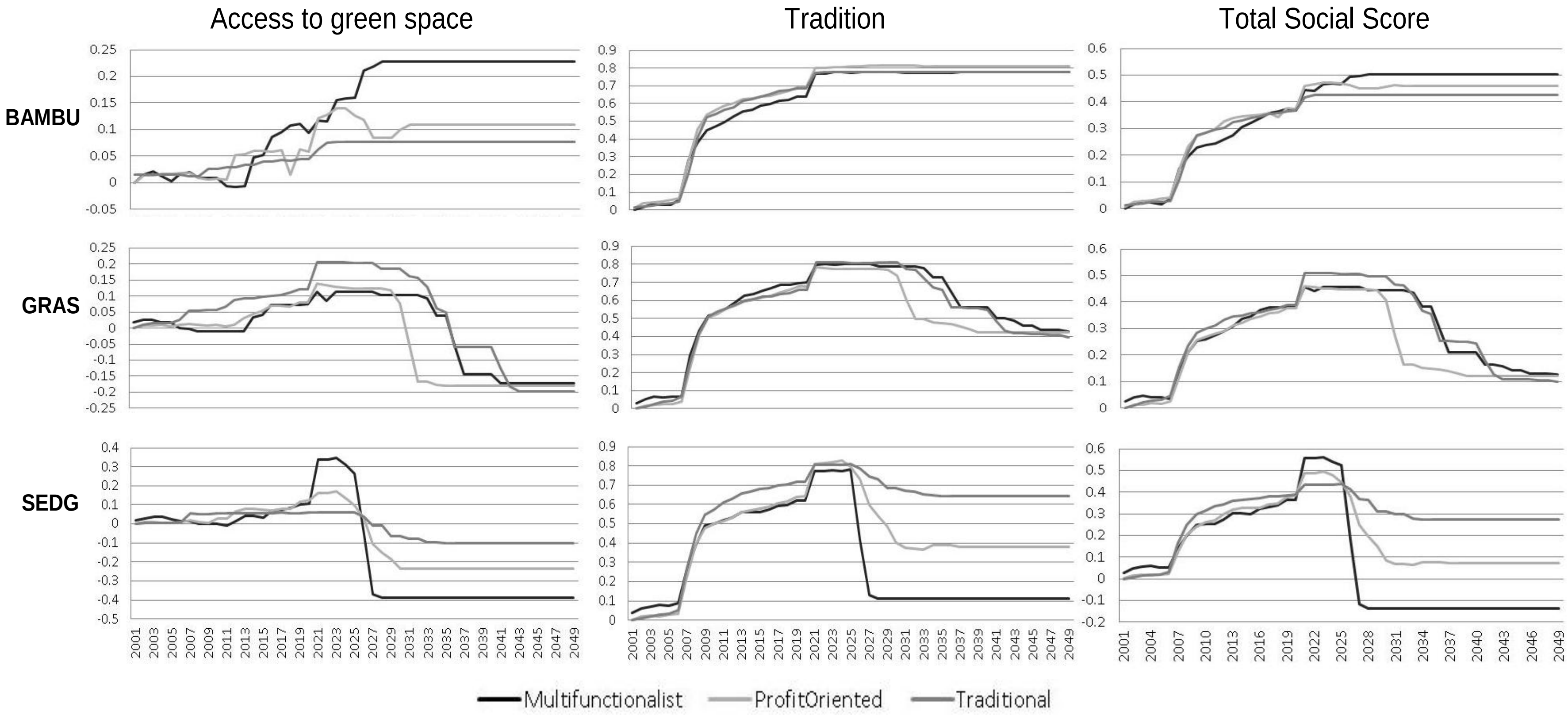

Figure 4.8 - Social indicator scores across time for Multifunctionalist, Profit-oriented and Traditional farmers in each scenario

The overall utility is largely dominated by the economic partial utility, in particular in the GRAS scenario (Figure 4.9). The environmental and social partial utilities are minor and similar in all scenarios since the space of the scoring system was bounded as opposed to the economic attribute. This reflects the economic adaptation of the different farmer types while maintaining maximised environmental and social utilities permitted by the potential regime alternatives that were input to the model. The estimation of utility over time is given in Appendix F and demonstrates different adaptation according to farmer types and scenarios. For instance, the multifunctionalists adopt a long-term plan strategy in BAMBU until 2030 (i.e. initial loss of profit in order to maximise it later), while the profit-oriented optimise their revenue on a one-year basis. The social utilities are negative in all cases while environmental utilities are positive or equal to zero. Profit-oriented farmers have higher environmental utilities than the multifunctionalists and traditionalists, showing the adoption of farm strategies with neutral environmental scores that satisfy the profit-oriented as opposed to the latter two groups for whom environmental utility increases as the scores attributed to regimes rise.

The profit-oriented farmers show an adaptation to farm strategies, which increase profit in BAMBU and GRAS. In contrast, the multifunctionalists chose strategies that break even in BAMBU or lead to profit loss in GRAS while not gaining environmental or social personal benefit. The traditionalists experience the smallest overall utility in both scenarios.

In SEDG, the pattern is reversed between profit-oriented farmers who loose profit and traditionalists who have managed to break even. The traditionalists maintain a positive utility, which emphasizes their characteristic of being satisfied without profit maximisation.

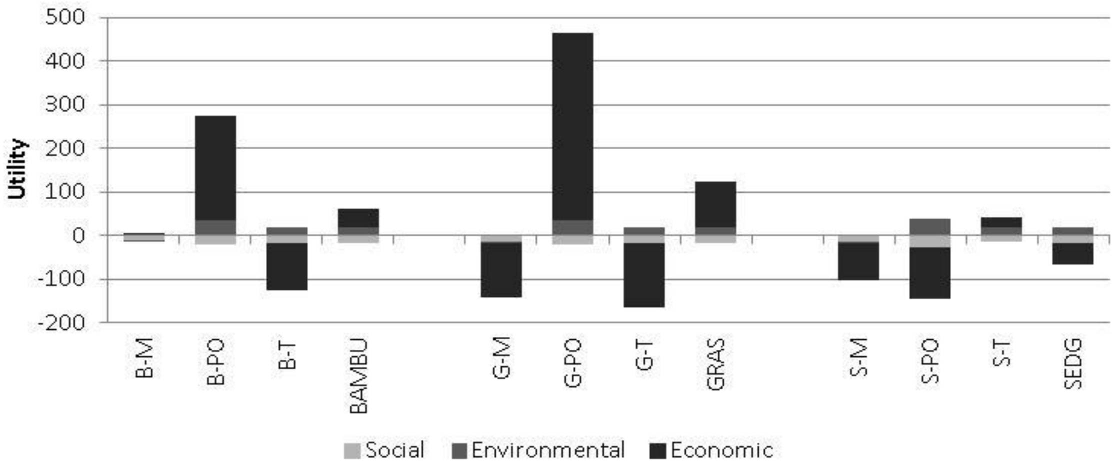

Figure 4.9 – Average partial utilities for economic, social and environmental attributes of farm strategies in the three scenarios, from 2008 to 2050 (B: BAMBU, G: GRAS, S: SEDG and M: Multifunctionalist farmers, T: Traditional farmers, PO: Profit-oriented farmers)

4. Discussion

4.1 Farmer types and behavioural change

Within a particular socio-economic context, farm strategies did not differ significantly between farm types, especially in the choice of land use types and management styles. However differences across the share of these choices allocated to farmland were more evident. In general, the multifunctionalists are more prone to adopt different land uses: AEMs, ecologically valuable spring-sown cereals, leguminous-based rotations and bioenergy crops. This suggests that the "innovativeness" describing this type of farmer could result from their preference structure towards a sustainable trade-off rather than their attitude to being less risky. In the same manner, traditionalist and profit-oriented farmers display similar strategies, although the underlying reasons are different, with a smaller proportion adopting newer technologies. The "conservatism" found in traditionalists and profit-orientation could also result from sustainable trade-offs. The exceptions may be that traditionalist systems are motivated by intrinsic values (social customs) and continue to provide socio-environmental sustainability whatever the context. This is shown by the poor overall utility of traditionalists in both BAMBU and GRAS, which becomes more prominent in SEDG, where socio-environmental sustainability is financially rewarded. According to their attitudinal profile, the high environmental scores obtained by the profit-oriented farmers are more likely to be maintained for utilitarian values rather than functional values (i.e. ecosystem service values).

In BAMBU, the land was generally intensively managed and grassland was converted to cereal-based rotations, with a switch from spring to winter sown cereals. These findings correspond to current expectations of the consequences of decoupling, e.g. decreases in livestock numbers, switching to growing highly priced commodities (CRER, 2004; Angus et al., 2009; Acs et al., 2010). In this scenario, the different types of farmers did not demonstrate any significant difference in behaviour, which seems to be essentially driven by policies. Nevertheless, the level of satisfaction differed significantly. The profit-oriented farmers had the highest overall utility, indicating adaptation of farm strategies towards profit-maximisation, from which approximately 38% comes from subsidies (36% from single farm payment and 2% from agri-environmental measures). Conversely, the multifunctionalists had a utility close to zero, although the highest compared with the other scenarios where overall utilities are negative. The financial supports that were offered for both production and other agri-environmental actions facilitated the optimisation of utility for these farmers, and a balance, between the sustainable attributes. Traditionalist farmers had the lowest utility, which is mainly due to loss of profit. Their farming strategies and positive resulting environmental outcomes did not depend heavily on agri-environmental schemes, but on their willingness to increase environmental and social values. This finding reveals the importance of this “active” group of farmers for maintaining the environmental and social features of a farming landscape if subsidies were to be abandoned.

In the GRAS scenario, input prices were low which leads to more intensive production of highly priced commodities. This situation forced all farmers to respond primarily to market signals by applying intensively managed short rotations or monocultures, i.e. from regimes with grass margins to bioenergy. In this scenario, the profit-oriented farmers have the highest utility because of their adaptation to market trends, while the other types experience negative utilities with profit loss. Despite the considerable socio-ecological benefits of increased land use diversity (due to higher market prices of root and leguminous crops), all farmers reduced the land allocated to activities historically attached (for Scotland) to the single farm payment, i.e. cereals. This would probably have different consequences with the dynamic hybrid model for England, in which payments are wholly area-based. In the Lunan, the disinterest for single farm payment would cause the environmental benefits of cross-compliance to only be met through the application of AES. It is then expected that, according to their attitudinal profiles, multifunctionalists and especially traditionalists would remain active in the maintenance of social and environmental values of the land without support mechanisms.

The largest behavioural change was observed in SEDG with the highest uptake of environmental schemes (particularly by the multifunctionalists), an extensification of production and the conversion of a significant amount of land to bioenergy crops. The economic aspect of the decision was less dominant on the overall utility of farmers, emphasizing the stronger influence of personal goals in strategy decisions over market and policy pressures. Simultaneously, because of the high price of inputs and the reduction from direct payments, farmers relied more on grants with environmental and social objectives. Production levels depended on the ability and decisions of farmers to reduce costs. Profit-oriented and multifunctionalist farmers opted for production with less intensive management (reduction of chemical input in the first case and grass margins in the second case) and this led to an overall utility which was negative. The traditionalists had a positive overall utility in SEDG by maintaining intensive regimes. In this scenario, farmers did not only trade-off between economic, environmental and social attributes, but they also made compromises between indicators that define an attribute. This highlights the importance of a common and correct definition of these attributes and the promotion of measures that include a variety of indicators. There is however a risk in developing further “less targeted” schemes since this could affect the farmers’ ability to participate if [s]he wants to favour a particular indicator.

The biggest change in average environmental and social scores appeared between 2020 and 2030 in all scenarios, suggesting a lag effect from the model to initiate behavioural change. One explanation could be the consequences of the economic shock of 2008-2010 when output prices, in particular cereal and oilseed rape, increased by more than 40%. From 2020, the simulated prices are more stable (Abildtrup et al., 2006). In addition, the lag effect could be due to the change of regimes of various lengths during the volatile period 2008 to 2020. Hence, from 2020, the results of the BAMBU and SEDG scenarios indicate that farmers apply the same regime(s) which correspond with the maximum utility specific to their behavioural type. In contrast the erratic scores observed in GRAS denote continual change in behaviour according to the volatility of output prices.

4.2 Agri-environment measures and bioenergy

The subsidies to income ratios have emphasized the accuracy of the model in representing the different motivations underlying AES uptake. While applying fewer regimes with AEMs than the multifunctionalists, the profit-oriented farmers made more profit from the scheme. This reveals the financial motives of the profit-oriented farmers when applying AES and the combination of financial, ecological and social reasons that explain the adoption of AES by the multifunctionalists. Traditionalist farmers are essentially driven by environmental and social objectives that can be reflected in strategies such as longer and more diverse rotations, without being tied to the application of AES.

In BAMBU, the adoption of agri-environmental measures (i.e. grass margins) is limited to times when gross margins are high, especially when regimes are attached to direct payments (Lobley and Butler, 2010). The farmer type-specific farm strategies in BAMBU were surprisingly analogous to the ones found in a previous study analysing past data related to the same farmer types (Chapter 3, section 3.3.2). In particular, the level of adoption of, and the relevance of agri-environmental subsidies to farm income corresponds well. The multifunctionalists were the most likely to adopt agri-environmental measures while the profit-oriented and traditionalists were reluctant. In the same manner, the profit-oriented farmers demonstrate the best profit from adoption in the past as opposed to traditionalist farmers. This is a positive note on the qualitative evaluation of the model (Schreiber, 2002; Bharathy and Silverman, 2010) and improves our understanding of the non-colinear attribute effects explaining actual behaviour in AES adoption (Adamowicz et al., 1994).

The removal of direct payment in GRAS and SEDG implies that all types of farmers rely on other subsidies, which can become a substitute mechanism for subsidising agriculture (Potter and Tilzey, 2007; Acs et al., 2010), especially for the profit-oriented farmers. However, in SEDG, profit-oriented farmers prefer to apply extensive regimes, for which no reward is distributed, to diminish the high costs of production in this scenario. The rise of bioenergy production in SEDG, which was encouraged by financial incentives, results in the withdrawal of the positive payoff by the application of extensive regimes and AEMs until 2025. This has antagonistic effects on the landscape, since the conversion of cropland to bioenergy is in conflict with the demand for food which is expected to increase sharply (FAO, 2009b) and the EU Renewable Energy Directive that necessitates the production of at least 15% of total energy by 2020 from renewables (Convery et al., 2012). Bioenergy crops can contribute significantly to the energy supply and, hence, to the reduction in greenhouse gas emissions (Bates et al., 2009), but have also raised concerns about the aesthetic quality of the landscape (Dockerty et al., 2012), the risk of genetic contamination (Byrne and Stone, 2011) and the loss of species habitats (Paterson et al., 2008). In particular, the preference for miscanthus over willow implies that more land of good quality is converted since it is a requirement for the latter to be viable (Wang et al., 2011). In GRAS, surplus land was made available due to a large increase in crop yield performance, but this is not the case in SEDG. The results have shown that if no financial support is given to farmers then the uptake of bioenergy cropping will remain stable and very low (e.g. in BAMBU). The economic viability of these crops, however, increased in all scenarios, but only the multifunctionalists were growing them over large land areas. A study by Sherrington and Moran (2010) has shown that, despite doubling the subsidy for the establishment of miscanthus, the level of uptake of bioenergy crops was not affected. Accordingly, the expected environmental benefit of this crop was the highest of all the regimes (apart from cattle-related regimes) and multifunctionalist farmers could therefore use bioenergy cropping to maximise their utility. This has demonstrated the importance of profitability (and subsidy) as a key factor driving all farmer types to switch to bioenergy crops (Lobley and Potter, 2004; Mattison and Norris, 2007).

4.3 Limitations of the method and future research

The conjoint experiment approach has proven valuable to disaggregate the utility of decision into different attributes, i.e. economic, environmental and social. This approach is however costly, time-consuming (for both preparation and completion), and requires rigorous attention from the participants. In this study, the number of returned completed questionnaires was very low even if reminder letters were sent.

Although the hierarchical bayes method for analysis is efficient to reduce the small sample size problem, the small sample still creates model uncertainties derived from the average partial utilities used to parameterise the farmer agents.

Since the model was designed so that the financial aspect of decisions had more weight, the values of environmental and social indicators could be interpreted as being the consequences of farmer choices rather than the reasons. In further development of the model, additional behavioural rules could be implemented which encompass cognitive processes. For instance the "consumat" approach of Jager et al. (2000) has proved successful in understanding agent interactions with the environment through four cognitive processes made by non-rational agents, i.e. repetition, imitation, innovation and adaptation. The use of empirical data from questionnaires and choice-experiments also do not allow the farmer types to be "adaptive", since the preference structure is not dynamic and the proportion of farmer types is constant (Robinson et al., 2007). Janssen and De Vries (1998) proposed a framework to represent the change in the proportion of agent types according to changing "world views". Such learning processes could be addressed in further development of the model to better anticipate how farmers will react to changing market and policy in the future.

The exploratory nature of the environmental and social indicators could have weakened the model outputs, but efforts were made to employ a scoring system previously developed by governmental agencies for the farmers to assess the sustainability of farming system. However, it seems evident from the analysis of the results that more indicators should be taken into account such as the level of greenhouse gas emissions from production and the diversity (and abundance) in animal species, particularly birds (Chapter 2). In this methodology we assumed that all farmers weigh a set of indicators equally when in fact the environment and society are not defined similarly for each individual or type of individual, and there might be a trade-off between indicators in decision making. More research is needed to define a correct representation of sustainability by farmers and to perceive specific relationships with farmer types. This could both improve the transparency of the model and have significant advantages in improving policy design to encourage specific farmer actions.

Although the integration of choice constraints based on historical data gives a sense of land quality, there is a lack of spatially-explicit emergent properties of the system being modelled. This aspect would be particularly interesting if the model was further developed to assess the provision of ecosystem services such as water quality, biodiversity, and landscape aesthetic. This could be further developed by linking preference structure to a land capability GIS-layer[21] (Appendices E and I, Figure I.2).

The farmer types were distributed randomly to the real farm boundaries. The concern for increased agricultural exit and land abandonment is particularly important in socio-ecological systems welfare (Lobley and Butler, 2010). Knowing the decision of the three types of farmers to continue farming is a priority in further developments of the model, but this requires the inclusion of demographic and farm structure data (e.g. farm size, age of farmers, tenancy).

5. Conclusion

The agent-based model presented in this paper was used to simulate farm strategy decisions by three types of farmers, profit-oriented, multifunctionalist and traditionalist, through a multi-attribute utility function reflecting the type-specific preference structure for sustainability. While most studies have tested the utility based solely on farm income and farm characteristics, this paper has shown that not all farmers would be satisfied, at least financially, in different socio-economic context; in particular, those farmers with environmental and social goals.

The results also highlighted the possible consequences of underlying farmer values and hence, on the effectiveness of policies to support sustainable agriculture. Therefore the proportion of farmer types within a landscape is particularly important to meet specific and sustainable targets.

The consideration and change of human values and preference structures in modelling land use change is therefore important for the development and the analysis of such models. This makes the farmer decision process more transparent and allows the analysis of model outputs to identify the winners and the losers in a particular context, and for re-balancing the benefits to all farmers.

[21] See footnote 6, page 52.

This raises a question of how farmers can be encouraged to change to more intrinsic values or, indeed, whether barriers to entry, which within farming are high, should be addressed. In the latter case, recent CAP reforms have allocated small proportions of money for encouraging younger entrants. However, ensuring these farmers have the most conducive set of values for promoting social and environmental values is really down to how these farmers engage with other actors in the landscape. Hence, advisory systems and policy prescriptions need to consider the wider impact on underlying farmer values for encouraging societal demands.

Chapter 5

Integrated ABM/IBM and ecosystem services outcomes

Adapted from Guillem, E.E., Murray-Rust, D., Robinson, D.T., Barnes, A., Rounsevell, M.D.A. *Modelling farmer decision making and trade-offs between ecosystem services***.** Submitted to Global Change Biology (2012).

Abstract

The provision of ecosystem services in farming areas is largely affected by individual farmer decisions which respond to a set of internal and external factors. In this paper, an agent-based model of heterogeneous farmer decision making was integrated with an individual-based model of skylark breeding population, and applied to a small intensive arable catchment in Scotland. The impacts of farmer decisions on a set of ecosystem services, i.e. food and bioenergy production, and skylark numbers, were simulated under the assumptions of three socio-economic and climatic scenarios until the year 2050. Bioenergy and food production had a significant negative effect on adult and fledgling skylarks. Food production was higher in the economic liberalisation scenario, due to intensive management and yield response to climate change and technological improvements. This explained the low average number of skylarks found at the landscape level in this scenario. This number was the highest in the sustainability-oriented scenario, however, a sharp decrease was observed from 2035 onwards due to the large area planted with bioenergy crops. The different values for economic, environmental and social attributes of farmer decisions played an important role in the land use mosaic, the implementation of ecologically-related actions and on the provision of ecosystem services. Overall, results suggest that a re-assessment of policy targets and design is necessary to maximise sustainable efficiency at the catchment level by taking into account the heterogeneity in farmer objectives and the trade-offs in ecosystem service provision. More research will be needed to analyse *ex-ante* the effects of farming practices on ecosystem service trade-offs at the landscape level.

Keywords: agent-based model; skylark; farmer decision-making; ecosystem services; land use change; model integration; bioenergy crops

1. Introduction

Land use and cover change (LUCC) is a major concern for the sustainability of farming areas and the provision of ecosystem services responsible for human welfare. Agricultural landscapes are largely shaped by human actions driven by socio-political and environmental stimuli (Antle et al., 2001; Lambin et al., 2001), and host a number of species that underpin the provision of ecosystem services. These species are under constant threat following changes in farming practices and management styles.

Land-related policies have been modified to prevent environmental degradation, but the reforms have created unexpected issues undetected in ex-ante analysis. For instance, the decoupling of payments for European farmers known as the Fischler Reforms, in 2005, was initially intended to reduce pressure on the environment, and has led instead to land abandonment in some areas, or intensification of arable land use, causing ecological degradation (EEA, 2004; IEEP, 2007; Acs et al., 2010; Holland et al., 2011; Doxa et al., 2012). In the near future, EU discussion documents have indicated that the CAP will tend towards liberalisation, which will create increasing reliance on fluctuating commodity prices and a possible switch from food to non-food production (Tranter et al., 2007), and lead to uncertain impacts on the sustainability of farming areas (European Commission, 2010). In addition, policy influences individual decisions in a complex way: food security, climate change mitigation and adaptation, the halt of biodiversity loss and sustainability of rural areas can involve conflicting objectives (EEA, 2006, 2007; Petersen, 2008). Therefore, the anticipation of consequences due to changing conditions (i.e. market, policy, climate) requires an improved understanding of how the internal processes of the system operate and when changes will occur.

Land-use activities and management result from farmer decisions and, when observed at the landscape level, are often heterogeneous. This heterogeneity has relevance in ex-ante analysis, but cannot be explained by common methodologies (i.e. linear programming) that do not take account of the cognitive behaviour of individual decision makers (i.e. attitudes, objectives, preferences) within a modelling framework (Edwards-Jones et al., 1998; Soman et al., 2008; de Chazal, 2010). In the same manner, the non-linear interactions between farmer decisions and the ecosystem, often acting at different spatio-temporal scales, cannot be considered independently since they involve feedbacks (Antle et al., 2001; Liu et al., 2007). At the landscape level, the aggregate land uses emerging from individual decisions have different impacts on a variety of ecosystem services and on species by providing or removing habitats. Farmland birds provide many of the ecosystem services proposed by the Millenium Ecosystem Assessment and the UK NEA (e.g. pollination, pest control, recreation, education, Whelan et al., 2008; Wenny et al., 2011). Specialised bird species, which require particular habitat to nest and to feed, have decreased drastically since the 1970s due to the intensification of agricultural land use (Siriwardena et al., 1998; Donald et al., 2002). The viability of bird populations is closely linked to farming practices and management and therefore the consideration of species abundance and diversity within socio-ecological systems is particularly relevant to the assessment of ecosystem health and the potential for services provided.

Over the past two decades agent-based models (ABMs) have increasingly been used to answer specific questions such as policy impact on farmer decisions and LUCC (e.g. Janssen et al., 2000; Berger, 2001), and the effect of LUCC on biodiversity and ecosystem services (e.g. De Angelis et al., 1998; Topping et al., 2003). The ABM approach considers actors who react autonomously to external pressures and interactions between agents and the environment, resulting in LUCC emerging from a bottom-up approach (reviews by Parker et al., 2003; Matthews et al., 2007; Robinson et al., 2007). In the same way, ecological, individual-based models (IBM) can simulate species population from the behaviour and life cycles of the individuals under different LUCC scenarios (McLane et al., 2011). In general, the current ABMs and IBMs lack transparency in some of the component sub-models that drive simulation outcomes. This can be improved by integration, or coupling, of an ABM of LUCC with an IBM, which offers greater potential to understanding processes and feedbacks between human and natural systems (Luus et al., 2011) and to studying the indirect effect of policy on ecosystem services through farmer decision making (Milner-Gulland, 2012; Sutherland and Freckleton, 2012). Only a few studies have presented results from such a combination (Jepsen et al., 2005; Bithell and Brasington, 2009; Verburg and Overmars, 2009), but the decision maker agents were not heterogeneous, which limits the relevance of such models since not all land managers react similarly to policies (Beilin et al., 2012).

This article proposes to integrate an agent-based model of farmer decision making with an individual-based model of skylarks, which is applied to a spatial (GIS) database representing a Scottish intensive arable catchment. The model represents relationships between external pressures (market, climate, and policy), heterogeneous farmer decisions about farming practices and the effects of these on ecosystem services (provisioning services: food production, renewable energy, and cultural service: skylark local population). A set of simulation experiments is carried out using three SRES-based scenarios (Spangenberg et al., 2012) to test the adaptation and responses of agents to changing contexts and the effects of this on the provision of ecosystem services.

2. Materials and Methods

2.1 Study site

The study area comprises 132 km^2 of a mostly arable catchment in the Tayside region, East Scotland (Figure 5.1). 115 active farmers manage the land with a mix of land use activities, essentially cereals and root crops (65%), and grasslands (35%) (JAC[22], 2007). The study area is one of the few places in Scotland where intensive cropping is possible due to a relatively flat and fertile soil. Farmers in the catchment share similar biophysical conditions, agricultural activities and market prospects, while avoids the problem arising from variations observed at larger scales.

This site has been intensively studied as it represents an example of a catchment with a number of typical indicators for Scottish farming and shows fragility in terms of water and air quality (Vinten et al., 2009 REF). Since 2003, the catchment has been designated as a Nitrate Vulnerable Zone (NVZ), which puts constraints on how farmers manage their land (Scottish Executive, 2003).

The catchment also includes a Site of Special Scientific Interest (SSSI) under the Nature Conservation (Scotland) Act 2004 (Rescobie and Balgavies Lochs), active fisheries, and the Balgavies Scottish Wildlife Trust reserve. In addition, the catchment forms part of the Scottish Environment Protection Agency's Monitored Priority Catchment Project, which aims to establish monitored baselines against which the effectiveness of diffuse pollution mitigation measures can be assessed (Vinten et al., 2009). Thus, the catchment and the broader region is of particular interest to policy makers.

[22] June Agricultural Census, source: Scottish Government.

Figure 5.1 - Location of the case study, the Lunan, in Scotland and farm (shaded colours) and parcels boundaries within the catchment (SIACS, 2007). (1590 parcels, min=0.03 Ha, max=85.86 Ha)

2.2 Model Development

The integrated ABM/IBM comprises four components:
1) A farmer decision making model, named “Aporia”;
2) An individual-based model of breeding skylarks;
3) A sub-model that estimates the energy produced from food and biofuel crops, and
4) A representation of the environment in which farmers and birds interact (Figure 5.2).

The spatial resolution of the model was the parcel level, which is delimited by boundaries and attached to a given farmer identity. Each parcel was updated on a daily basis given a certain crop type for vegetation structure. Farmer attributes and decisions, and crop yields, were updated annually while skylark behaviour, life-cycle characteristics and vegetation heights were simulated daily. Temporally, both the ABM and IBM were only loosely coupled since the time-step of a changing state was asynchronous (Antle et al., 2001; Bithell and Brasington, 2009). The two models were fully integrated at the parcel level. The model was run for a period of 50 years, with calibration based on historical data of land use change for the period 2000 to 2008.

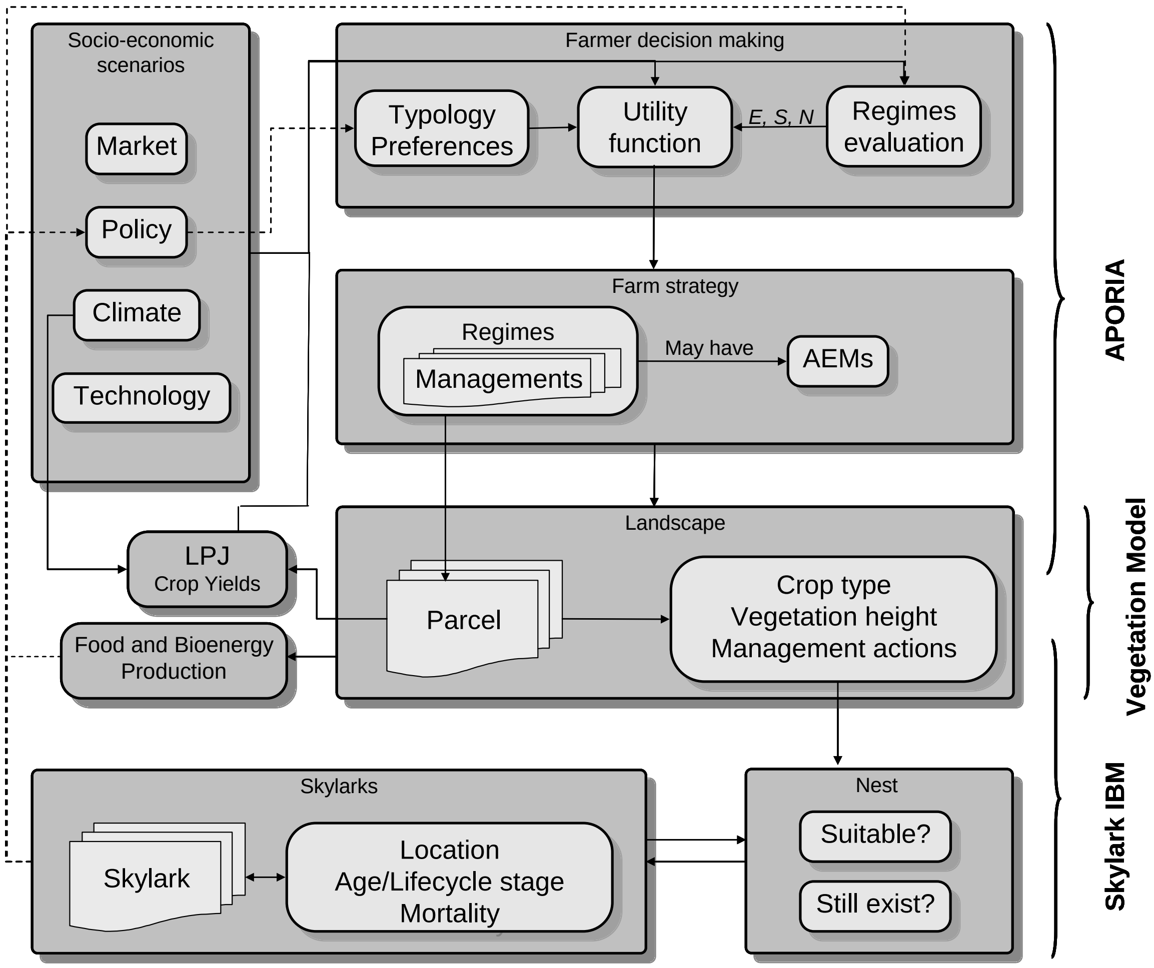

Figure 5.2 – Conceptual framework of the integrated ABM/IBM. The dotted lines represent feedbacks that are not implemented in the current version of the model.

2.2.1 Farmer decision making

Aporia is an agent-based model of farmer decision making (Murray-Rust et al., 2011, 2012; Guillem et al., 2011; Robinson et al., 2011; Chapter 4 section 2.2). The model represents heterogeneity in decision making in terms of farm strategies, i.e. land use regimes per farm. A farmer chooses a regime, i.e. crop rotation, for each of the parcels that compose the farm, the management style associated with it (intensive or extensive) and whether an agri-environmental measure or the conversion to bioenergy crops is applied. It is assumed that these choices are based on attitudes and preference structures for the sustainability principles, i.e. economic viability, environmental quality and social well-being (Chapter 4 section 2.2.1).

A sample of farmers within the Lunan catchment was selected for a phone interview and the results used to obtain three clusters of respondents: Profit-oriented, Multifunctionalist, and Traditionalist (see Chapter 3 for further details).

Profit-oriented farmers (38%) expressed interest in maximising profit from the available resources. They did not have strong positive attitudes towards the environment or to society. Traditionalist farmers (36%) optimised lifestyle factors, which encompass environmental and social quality. These conservative types showed a preference for maintaining similar strategies through time. The multifunctionalists (25%) considered profit-maximisation as well as environmental and social objectives equally. They had strong values for the environment and participate in AES. They innovated if this fitted with market and policies changes.

The preference structure for the sustainable attributes of a regime was elicited for the farmers' types from a choice-based conjoint survey (see Chapter 4 section 2.2.1; Appendices D and E) and implemented in an aggregative linear utility function. A regime evaluation method was used to rank a set of alternative regimes from which farmer agents select the one that maximises their utility. This method computes an economic (difference in gross margins), environmental (cover, nitrogen use and diversity) and social (access to green space and tradition) score for each regime (*ibid*). The associated farm level characteristics of each farm type defined the proportion of land use within the catchment that these agents would manage. Within their own proportion, each farm was randomly allocated and associated with farm parcels to reflect their farming land use profile.

2.2.2 Skylark IBM

The skylark model was designed to represent the population of birds from individual breeding behaviour within the Lunan catchment with respect to farmer cropping choices. The skylark *Alauda arvensis* is a common farmland bird that provides cultural services (i.e. identity, recreation, education), and responds within predictable parameters toward changes in LUCC, i.e. focal species (Lambeck, 1997). A large literature was available on the species breeding ecology, which is linked to farm management (Chamberlain et al., 1999).

The skylark nests within crops from early April to the end of July and can breed up to four times during the same year depending on the suitability of a nesting site (Chamberlain et al., 1999). Nest suitability and length of the breeding season depend mainly on vegetation structure (*ibid*), which is influenced in the model by crop type. In the model, bird territories (comprising the nest and a circular area around this from which birds forage) were selected by males until a maximum carrying capacity of the landscape was reached. The model was therefore parameterised against territory density per unit area. These values were given for each crop type found in the Lunan catchment and taken from a field survey of the Lunan catchment carried out in 2009 (Table 5.1, Unpublished data; see Appendix G for field survey method and analysis).

Table 5.1 – Parameters and values for the suitability of nest sites. *T* is the maximum territory density per hectare

Parameters	Value	References
Vegetation height	Min=10cm; Max=120cm	Own field survey[a]
$T_{WinterWheat}$	0.141	Own field survey[a]
$T_{SpringCereal}$	0.135	Own field survey[a]
$T_{WinterBarley,Oat}$	0.077	Own field survey[a]
$T_{OilseedRape}$	0.062	Own field survey[a]
$T_{RootCrops}$	0.091	Own field survey[a]
$T_{Legumes}$	0.173	Own field survey[a]
$T_{GrassMowing}$	0.072	Own field survey[a]
$T_{IntensiveGrazing}$	0.084	Browne et al., 2000
$T_{ExtensiveGrazing}$	0.101	Browne et al., 2000
$T_{RoughGrazing}$	0.059	Browne et al., 2000
$T_{Miscanthus}$	0.030	Sage et al., 2010
T_{Willow}	0.095	Sage et al., 2010
$T_{SetAside}$	0.360	Browne et al., 2000

[a] See Appendix G

Territory densities can be used as proxys for feeding resources for chicks, i.e. invertebrates, with regards to land use type (Ebersole, 1980; Poulsen, 1996). When a crop was extensively managed or associated with grass margins, the density was upgraded by up to 20% to represent less dense structure and the higher availability of invertebrates that permits smaller territory sizes (Henderson et al., 2009). Sites where skylark territories were found during the field survey had a vegetation height comprised of between 10 to 120 centimetres, which were set as a minimum and maximum vegetation height requirement in the model.
When entering the breeding period, a male agent "scaned" a search space of 500 metres of diameter (approximately 78 hectares), and assessed the capacity of the landscape for establishing a nest, i.e. establishing enough available space with suitable vegetation heights. The maximum capacity was determined by multiplying the area of crops in the search space by their specific territory density. The scanned area thus considers habitat diversity with associated weights related to crop types (see also Chamberlain et al., 1999). If the number of territories currently occupied did not exceed the maximum capacity, the male set its nest in a suitable place and attracted a female. Once a male had selected a site, the site remained occupied until the male or its partner dies. In the same manner, if the vegetation structure changed and was no longer suitable, the pair sought another site or became "floaters", i.e. non-reproductive flock of birds.

It was assumed that every adult had a reproductive capacity and that the sex ratio was 1:1 (Fisher, 1930; Dougall, 1997). The number of individual floaters was not initially set but emerged from simulations when some adults were unable to find a nest or a partner (due to the depletion of suitable territory or to the death of a mate). Individual skylarks were characterised by a set of variables related to their life-cycle traits (Table 5.2), which were dynamic variables recorded daily throughout the simulations. Mortality rates were normally distributed within different life cycle stages from empirically-determined distributions (i.e. egg, nestling, fledgling and adult). Life-cycle stages were classes with their own attributes and rules. When a pair established a nest, mating occured and 5 days later eggs were laid at one day intervals from the first egg (Delius, 1965; Wilson et al., 1997). The incubation period lasted 11 days (Wilson et al., 1997). After hatching, the nestlings were cared for by the parents for a period of 10 days (Wilson et al., 1997). The nestlings leave the nest and become fledglings for 9 days (Delius, 1965). At this stage the fledglings were still under the care of their parents (Poulsen, 1996), who started a new breeding attempt only when the fledglings are 19 days old (Delius, 1965). The behavioural rules applied to the young stages, i.e. egg, nestling and fledgling, were limited to "Start" and "Die". However, each stage had a specific probability of mortality, which denoted the level of survival found in the literature. Some values held constant, such as maximum longevity, age of maturity, length of life cycle stages and number of eggs laid. Figure 5.3 shows the daily sequence of events applied to each individual adult. In winter, the birds floated randomly in the catchment until a new breeding season starts.

Table 5.2 – Parameters and values of life cycle traits in skylarks used in the model

Parameters	**Value**	**References**
Age of maturity (days)	300	Delius, 1965
Territory search space	ø 500m	maximum territory size ø 250m, Odderskaer et al., 1997
Number of eggs laid	4	Delius, 1965; Robinson, 2005
Daily probability of egg mortality[a]	0.0293	Chamberlain and Crick, 1999
Daily probability of nestling mortality[a]	0.0536	Chamberlain and Crick, 1999
Daily probability of fledgling mortality[a]	0.027	Poulsen et al., 1998
Daily probability of adult mortality (breeding season)[a]	0.00197	Wolfender and Peach, 2001
Daily probability of adult mortality (winter)[a]	0.00275	Topping et al., 2005
Lifespan (days)	max 3285	Staav and Fransson, 2008

[a] These values are transformed from yearly rate (S) to daily rate (d) using the following equation: $d = 1 - (S^{(1/n)})$, with n the length of a given lifecycle stage (days).

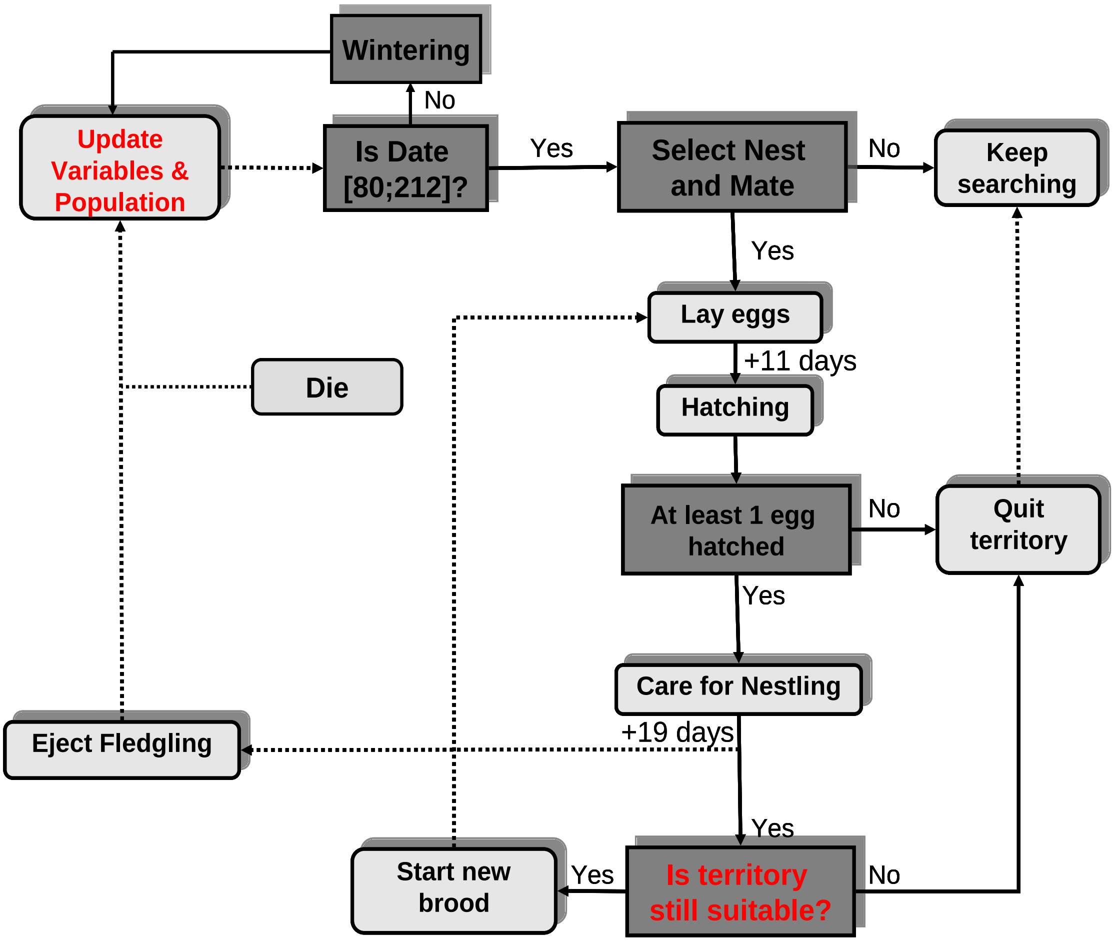

Figure 5.3 – Behavioural rules applied to individual adult skylarks

2.4 Biophysical entities

The environmental factors (e.g. vegetation heights, timing of farming actions) were driven by land-use type and farmer management actions. The land-use types determined the vegetation structure (i.e. height), the maximum capacity of nesting and the utility a farmer obtained each year. Farm management actions were limited by fixing dates for sowing and harvesting. The dates and the initial average yields specific to a management action were taken from the literature available for Scotland (FMH[23], various years).

[23] Farm Management Handbook is edited by SAC and provides a variety of information on the UK arable and livestock sector (e.g. detailed gross margins calculation).

Two vegetation models were used simultaneously: one provided a daily update of each parcels vegetation height and the other gave harvestable biomass for each year based on crop and soil types, and climate variables specific to the region (from LPJ-Guess Integration: Sitch et al., 2003; Bondeau et al., 2007).

The vegetation height model used different equations depending on land use. For crops, a daily growth curve was used based on empirical information collected during the bird survey (Figure 5.4). If a parcel was abandoned, a natural succession of shrub vegetation took place, for which the height of vegetation H at time t was modelled using the Chapman-Richards equation (Equation 1).

$$H(t) = A + \frac{(K - A)}{(1 + Q.e^{-B(t-M)})^{1/v}} \quad \text{Eq. 1}$$

, with A and K respectively the lower and upper asymptote ($A=0$, $K=150$cm), B is the growth rate ($B=0.02$), v is the nearest line between lower and upper asymptote ($v=0.5$), Q depends on the value at $H(0)$ and M is the time of maximum growth when $Q=v$.

Future climatic variations were simulated by global climate models as a response to GHG and aerosol emissions (Mitchell et al., 2004). The latter corresponds with the IPCC-Special Report on Emissions Scenarios (SRES), which were associated with the ALARM scenarios (GRAS, BAMBU, SEDG respectively with A1F1, A2 and B1) (Fronzek et al., 2012).
The LPJ-Guess model was used *a priori* to simulate vegetation biomass using standard crop functional types (CFTs) for each of the SRES scenarios and for the whole case study, which was considered biophysically uniform. On a yearly basis, the biomass of each CFT was extracted and was loaded into the ABM.

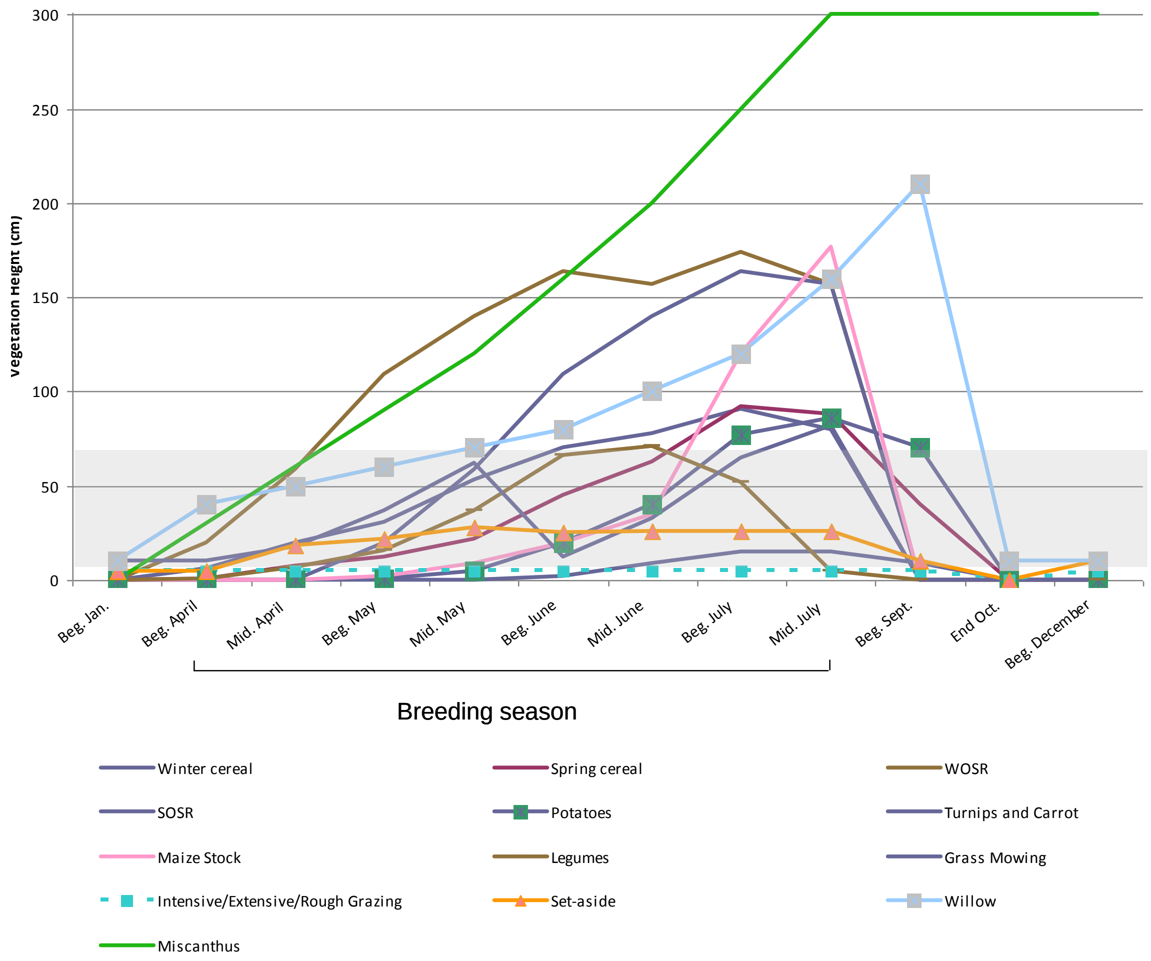

Figure 5.4 – Crop vegetation curves derived from survey data. The darker grey represents the suitable vegetation height for skylark nest establishment (10-120 cm)

2.5 Food and bioenergy production

The harvesting of food for human consumption (i.e. vegetables, potatoes, cereals) and bioenergy crops (i.e. willow and miscanthus) was converted at each annual time-step into energy produced from the whole catchment. This was done by multiplying the amount of commodity harvested (in tonnes) by the energy value for human consumption and renewable energy using FAO and USDA conversion coefficients

(Table 5.3). The simulation outputs gave a cumulative sum of energy produced in the catchment.

Table 5.3 – Energy conversion from food and bioenergy products

	Energy (MJ/ton)	Reference
Wheat	13975	FAO[a]
Barley	13891	FAO[a]
Oat	16108	FAO[a]
OSR	20669	FAO[a]
Potatoes	32217	USDA[b]
Turnips	15062	USDA[b]
Carrots	30125	USDA[b]
Peas	33890	USDA[b]
Beans	28033	USDA[b]
Willow[c]	17200	Valentine et al., 2008
Miscanthus	17000	Natural England[d]

[c] net energetic value of wood at 35% moisture. value in MJ/oven dried ton
[a] http://www.fao.org/economic/ess/ess-data/ess-fs/ess-nutritive/en/
[b] http://www.ars.usda.gov/SP2UserFiles/Place/12354500/Data/SR23/reports/sr23fg11.pdf
[d] http://www.naturalengland.org.uk/Images/miscanthus-guide_tcm6-4263.pdf

2.5 Socio-economic scenarios

The ALARM scenarios represent coherent relationships between socio-economic contexts and the resulting climatic impacts (Audsley et al., 2006; Bohunovsky et al., 2011; Settele et al., 2012; Spangenberg et al., 2012). Three socio-economic scenarios GRAS (Growth Applied Strategy), BAMBU (Business-As-Might-Be-Usual) and SEDG (Sustainable European Development Goal) were initially developed to assess large-scale risks to biodiversity and mitigation options. The narratives were refined for the case study specifically for the agricultural sector. A short description of the different policy frameworks is given here with more details provided elsewhere (Bohunovsky et al., 2011; Spangenberg et al., 2012). In BAMBU, the current economic and policy situation is maintained with a progressive shift of funds from the CAP pillar 1 (production) to pillar 2 (environmental enhancement). In GRAS neither direct payments nor rural development funds are proposed from 2020. The

SEDG scenario portrays environmental and social development and therefore farmers are encourage through financial incentives to grow bioenergy crops, to use more extensive management and to apply agri-environmental measures.

2.6 Initialisation and analysis of simulation results

The model was initialised with the historical spatial arrangement of land use from 2000 to 2007 using IACS[24] data. The initial population of skylarks was estimated from the carrying capacity of the 2007 historical landscape.

Because the model was stochastic, multiple simulations were performed; 10 for each scenario, with a proportion of farmer types corresponding to the results of the social survey (ALL). Another 10 runs were computed for each of the three scenarios, but the farmer agent population was represented by a unique type (Multifunctional, Profit, Traditional).

Model outcomes were analysed to test the relationships between the production of food as well as bioenergy (in constant energy units, megajoules (MJ)) against the adult and fledgling population of skylarks, using a linear mixed model to account for temporal autocorrelation, i.e. 30 points, related to the 10 simulations for three scenarios, were clustered per year, giving 42 groups (i.e. the 42 groups were the 42 years of simulations) for 1260 observations. The model was computed in R using the “nlme” package (Pinheiro et al., 2009). The linear mixed model had the following form (Laird and Ware, 1982):

$$A_{i,j} = \beta_1 \cdot x_{1,i,j} + \dots + \beta_n \cdot x_{n,i,j} + t_{i,1} \cdot z_{1,i,j} + \dots + t_{i,p} \cdot z_{p,i,j} + \varepsilon_{i.j} \quad \text{Eq. 2}$$

$$t_{i,k} \sim N\left(0, \psi_k^2\right), Cov\left(t_k, t_{k'}\right) = \psi_{k.k'} \quad \text{Eq. 3}$$

$$\varepsilon_{i,j} \sim N\left(0, \theta^2 \cdot \lambda_{i,j}\right), Cov\left(\varepsilon_{i,j}, \varepsilon_{i,j'}\right) = \theta^2 \cdot \lambda_{i,j,j'} \quad \text{Eq. 4}$$

[24] See comment 10, p. 84

where $A_{i,j}$ is the resulting number of skylarks for observation *j* (*j* = 30) of cluster *i* *(i =42),* $\beta_1 \ldots \beta_n$ are the fixed effect coefficients constant across clusters, $x_{1,i,j} \ldots x_{n,i,j}$ are the fixed effect regression coefficients, $t_{i,1} \cdots t_{i,p}$ are the random effect of time coefficients of cluster *i*, $z_{1,i,j} \cdots z_{p,i,j}$ are the random effects regression coefficients, $\varepsilon_{i,j}$ is the error term, $\psi_{k.k'}$ are the covariances among the random effects and are constant across clusters, $\theta^2 \cdot \lambda_{i,j,j'}$ are the covariances between errors in cluster *i*.

For the ALL simulations, a time series (2000 to 2050) of the cumulative sum of energy produced, averaged over the 10 multiple simulation runs, and of the average number of adult and fledgling skylarks, were compared across each scenario.

Finally, the geometric means over 10 simulations from the year 2008 onwards of adult skylarks was used to compare skylark populations in a landscape managed exclusively by a single farmer agent type (Multifunctional, Profit, Traditional). Kruskal-Wallis tests were carried out on the null hypothesis that skylark numbers were statistically similar across farmer types.

3. Model outputs

3.1 Trade-offs between ecosystem services

The linear mixed model shows that both bioenergy and food production have a negative fixed effect on the number of skylarks and fledglings when considering potential variation due to time (random effect) (Figure 5.5). The fixed effect of the explanatory variables, food and bioenergy production, is the average effect over all years of the simulation. The fixed effect of biofuel production against adult and fledgling numbers is significant (respectively, t (Df=1246) = -3.785, $p<0.001$ and t (Df=1246) = -6.783, $p<0.001$), with a negative effect occuring when the production exceeds approximately 10 terajoules. Similarly, the linear relationship between food production and adult and fledgling skylark numbers is also significant (t (Df=1246) = -4.053, $p<0.001$ and t (Df=1246) = -3.868, $p<0.001$), though the fitted regression line is less abrupt than for bioenergy.

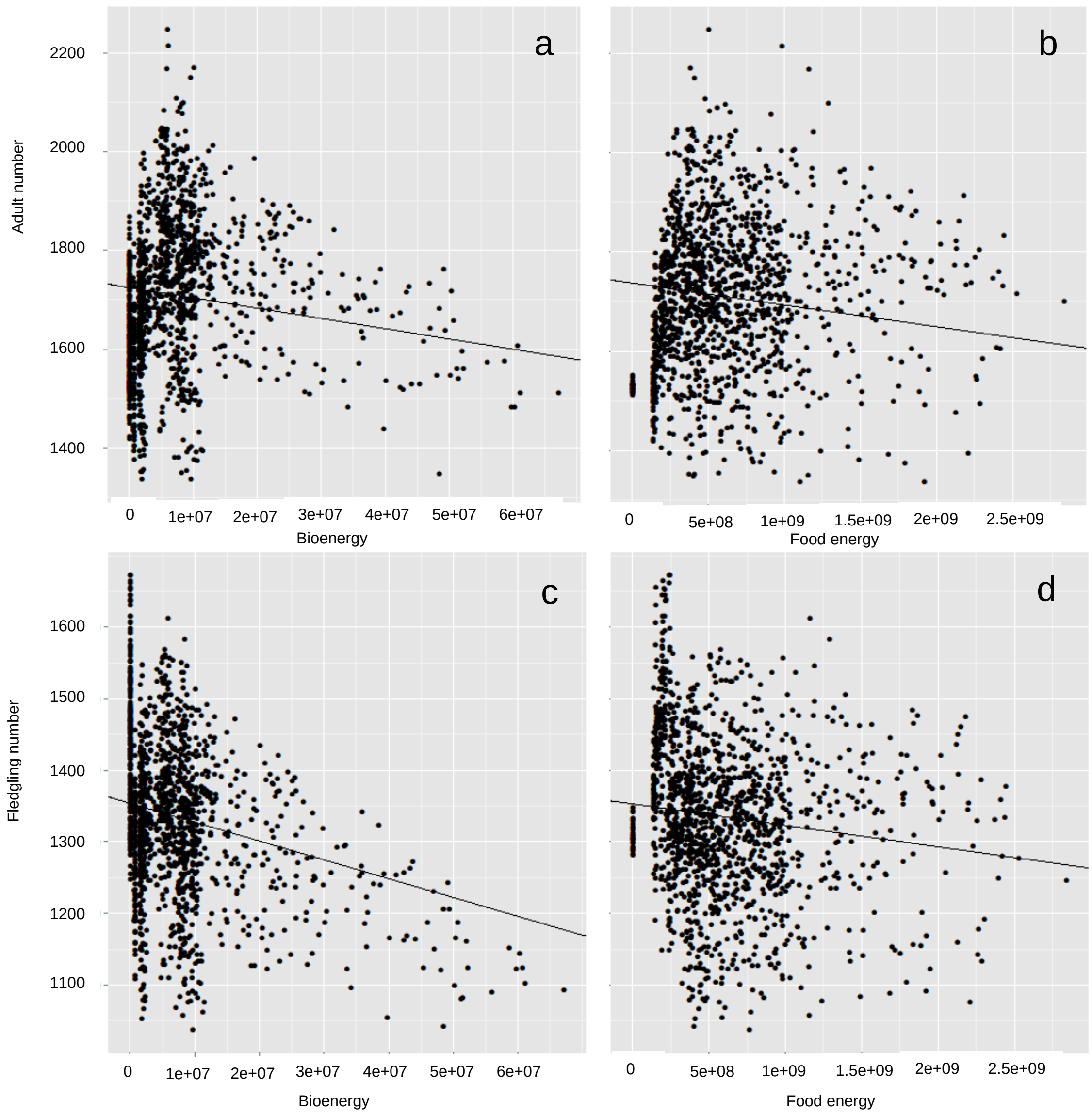

Figure 5.5 - Relationship between number of adult skylarks and a: Bioenergy produced, b: Food energy produced; and between number of fledglings produced and c: Bioenergy (MJ), d: Food energy (MJ)

3.2 Ecosystem services across scenarios

The mean density of skylark territories over the period 2008-2050 was 0.13 per hectare and there were no significant differences between scenarios. Studies carried out on arable lowlands have found a similar result, 0.11/Ha (O'Connor and Shrubb, 1986), 0.12/Ha (Poulsen et al., 1998). However the trends in population are different across scenarios (Figure 5.6 a), although there is an increase up to 2030 in all scenarios because of the high proportion of cereals grown compared with the baseline years 2000 to 2007.

In BAMBU, the population of adult skylarks increases until a plateau is reached between 2020 and 2040, followed by a small decrease afterwards. In this scenario the energy produced from miscanthus is the lowest, and does not exceed 10 terajoules (TJ), while energy from food is intermediate compared with other scenarios (Figure 5.6 c and d). The proportion of crop types changes slightly at each decade (Figure 5.7), with an increase in root crops due to higher yielding performance, loss of set-aside and grassland[25]. However, the level of cereals is higher than in the other scenarios and the area planted with miscanthus remains low. In GRAS, the adult skylark population is the lowest (until around 2040), with the highest production of food products compared to the other scenarios. In this scenario, the area grown under cereals, which has the highest territory density, is cut by 35% by 2050 (Figure 5.7). This is replaced by root and bioenergy crops. Yield improvement and the resulting response from low input and output prices in GRAS allow more land to be converted to bioenergy crops without diminishing food production. The number of adult skylarks reaches a maximum level in SEDG around 2030 while the most abrupt decrease is observed afterwards. In SEDG the production of bioenergy is highest and accounts for more than 50 TJ in 2050, while the production of food is the lowest. The decrease in adult and fledgling skylarks is initiated before the amount of bioenergy produced goes beyond 10 TJ and is very abrupt, as opposed to the GRAS scenario where the decrease starts later and is smoother.

In figure 5.6b, the number of fledglings produced diminishes in all scenarios over the whole period. A small increase is observed from 2020 in GRAS and SEDG when direct payments start to be reduced (drastically in GRAS and more progressively in

[25] GIS-based maps showing the simulated distribution of land-uses in the study area in two time slices, 2025 and 2050, under the assumptions of three scenarios GRAS, BAMBU, SEDG, are provided in Appendix H.

SEDG). The only difference found in 2020 between GRAS, SEDG and BAMBU, is a greater diversity of crop types in GRAS and SEDG, i.e. presence of leguminous crops and miscanthus (Figure 5.7).

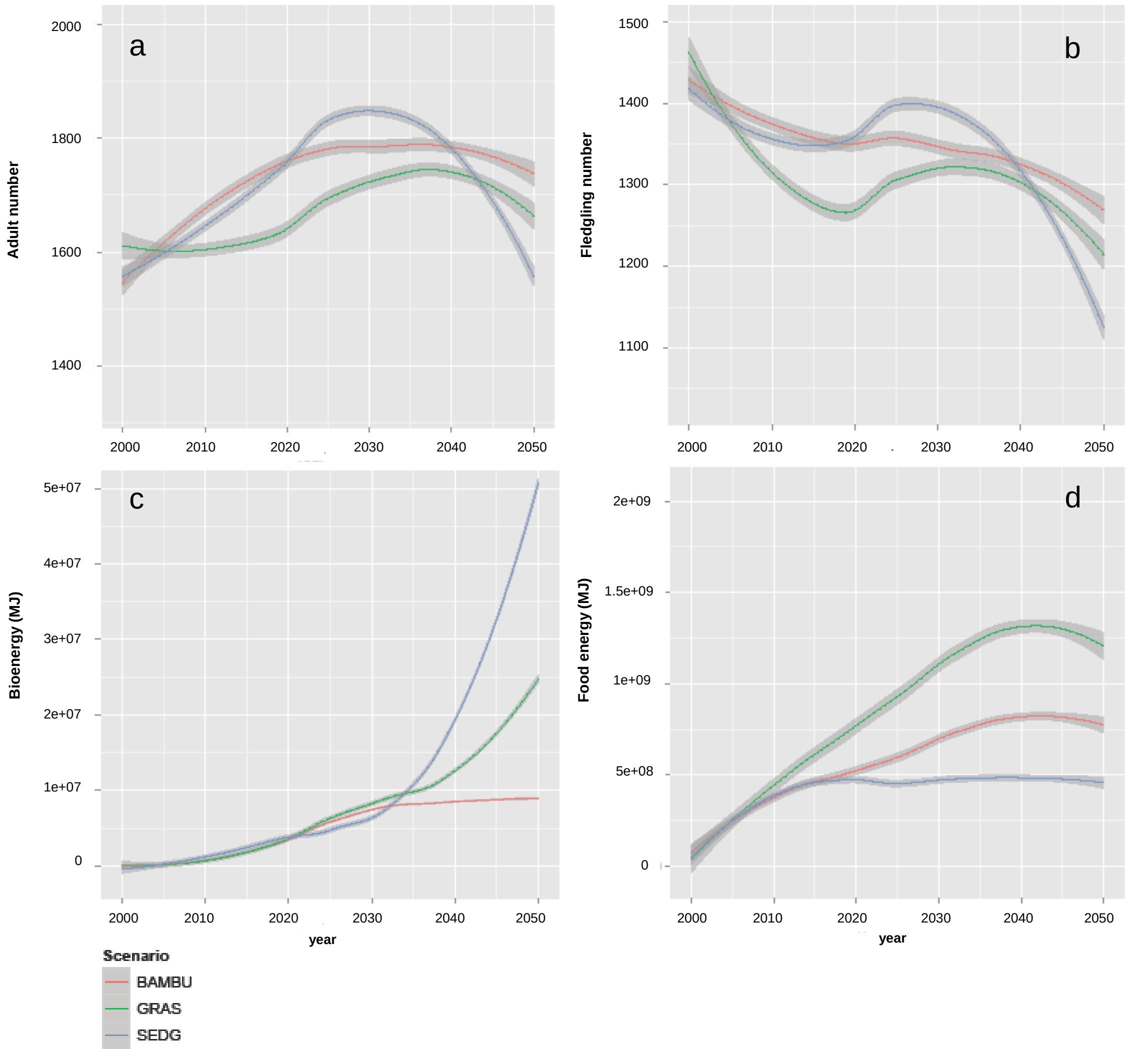

Figure 5.6 - Ecosystem services for the three ALARM scenarios, a: Average number of adult skylarks (age>300 days), b: Average number of fledglings produced, c: Bioenergy (MJ), d: Food energy (MJ)

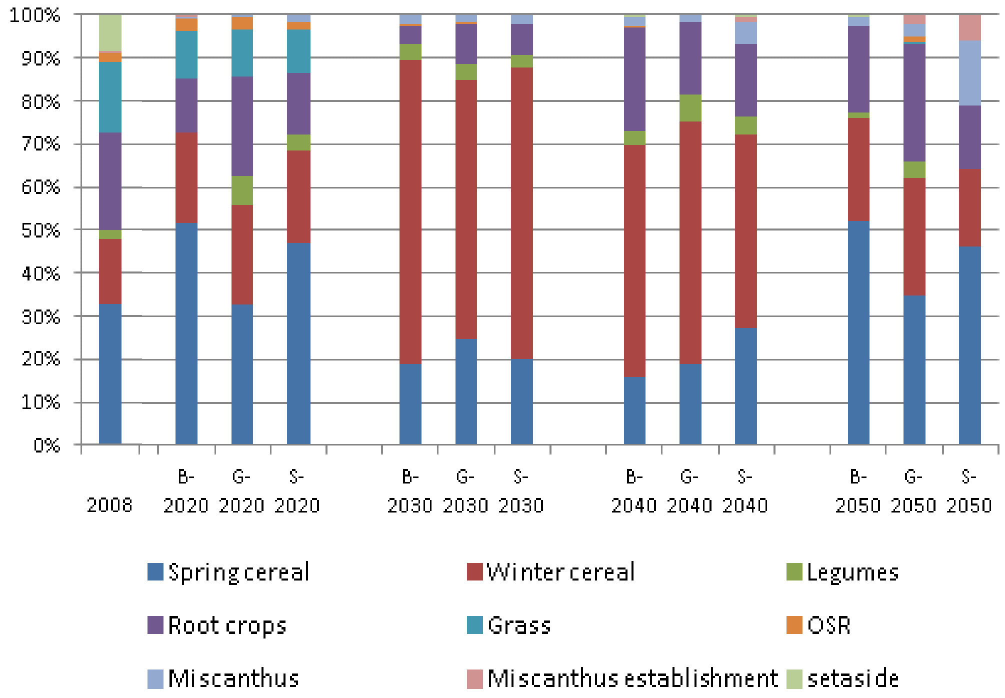

Figure 5.7 – Proportion of land cultivated by the different land use types considered in the model under the three scenarios, B: BAMBU, G: GRAS, S: SEDG

3.3 Effect of farmer behaviour on skylark population

Kruskal-Wallis tests were performed to test the distribution of adult skylarks across different landscapes virtually managed by each farmer type separately. The average number of skylarks over the period 2008-2050 was significantly different across the three types of landscapes (BAMBU: p=0.007, GRAS: p=0.000, SEDG: p=0.002) (Figure 5.8).

In a landscape managed exclusively by traditionalist farmers, the number of adult skylarks remains the same in the three scenarios, while there are some variations in the case of profit-oriented and multifunctionalist farmers. For profit-oriented farmers, the average number of skylarks is the highest in BAMBU, but the lowest in GRAS. For multifunctionalist farmers, the abundance is similar to the traditionalists in BAMBU and GRAS, but decreases in SEDG.

Multifunctionalist farmers generally apply environmentally-friendly practices, i.e. grass margins and spring cereals, but they also adopt newer technology such as bioenergy crops (Chapter 4 section 3.2.1). This could explain the low abundance found in the SEDG scenario after 2030, in which subsidies allow bioenergy crops to be viable. The profit-oriented farmers grow cereals in BAMBU, but they manage their land more intensively and the crop mosaic is less diverse in GRAS. This type of farmer was the most proficient in adapting to rapidly changing market conditions to maximise profit. Traditionalist farmers maintained intensive regimes in all scenarios, but they use longer and more diverse crop rotations (see Chapter 4). In addition this type of farmer was the least likely to apply bioenergy crops. The average number of skylarks in a landscape managed by all types of farmers was very similar to those for the profit-oriented types for both BAMBU and GRAS.

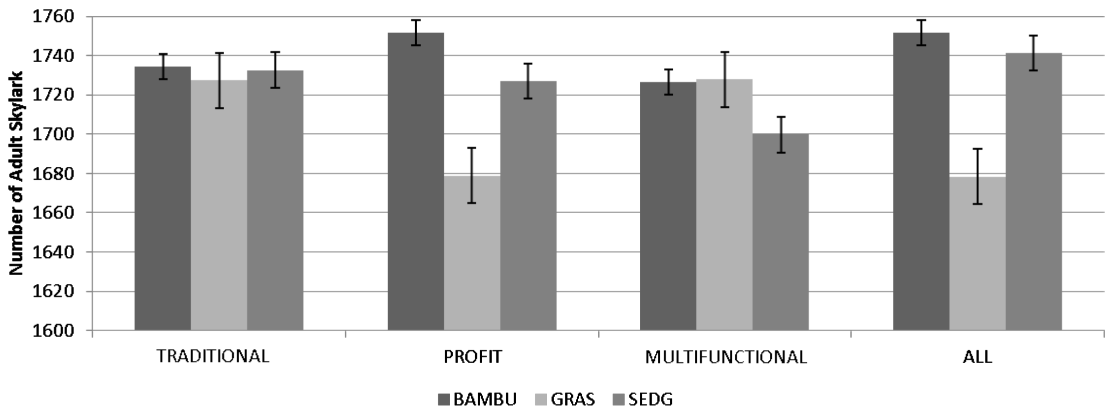

Figure 5.8 - Average number of adult skylarks over the 2008-2050 simulation period in a landscape managed exclusively by multifunctionalist (MULTIFUNCTIONAL), profit-oriented (PROFIT), traditionalist (TRADITIONAL) farmers, and in the landscape managed by the actual population of farmers (ALL)

4. Discussion

This paper addresses the impacts of large-scale socio-economic pressures on the provision of ecosystem services (i.e. skylark number, food and bioenergy production) through a land use cover change model where actors' decisions are explicit and empirically informed. We showed how the landscape level dynamic arrangement of crop types and rotations can affect the local population of skylarks and how a complex definition of differing farmer decision making processes can play a role in understanding land use change.

4.1 Negative effect of food and bioenergy production on skylarks

The study revealed a negative effect of bioenergy and food production on adult and fledgling skylarks. In mid-May, during the middle of the breeding period, the height of miscanthus is no longer suitable and the birds have to seek other territories (see Figure 5.4). It is possible that, at this period, most of the adjacent fields are already occupied leading these birds to become non-reproductive floaters. This was verified by the more severe decrease in fledgling numbers when the production of bioenergy increases, meaning that the breeding period is shortened and less breeding attempts will occur. However, previous field studies related to bird and bioenergy crops showed that miscanthus supports a higher density of breeding skylarks than other arable crops, but at an early stage of crop establishment when the vegetation does not exceed a maximum threshold (Semere and Slater, 2007; Bellamy et al., 2009; Sage et al., 2010). The high skylark density found in the literature was explained by a significant proportion of bare ground and the presence of weeds on which adults feed. Hence, if bioenergy cropping becomes increasingly viable, there is a risk that improved technology aiming at maximising yields will lead to the loss of these benefits. Since high density of skylarks only occurs at the beginning of the breeding season in miscanthus, it is also evident that a certain degree of crop diversity should be maintained for the birds to continue breeding in adjacent fields (Chaney et al., 1997).

The provision of food is also shown to have a negative impact on skylarks. In contrast to bioenergy, this relationship is not a function of the area planted with food crops. A large area planted with food crops is in fact advantageous for skylarks, but the intensity at which these crops are managed has more impacts. Donald et al. (2002) found a negative relationship between yield improvement and population trends of farmland bird. This is difficult to measure in ecology-based studies since food crops are very diverse and offer a variety of habitats. Nevertheless, it is particularly relevant to test the effect of policy targets, in particular food security, by quantifying both the level of food and energy required at the European and regional levels, and the variations this induces in the abundance of birds. With further intensification and an increase in yield performance due to technology and climate change, the risk increases for the viability of skylark populations.

4.2 Impacts of socio-economic contexts on ecosystem services

In all scenarios, an increase in skylark numbers is observed at least until 2030. This is explained by the choices most farmers make to increase the cultivation of cereals compared with the area planted in the baseline year 2008. Cereal crops have been defined as “the single most important habitat for skylarks in the UK in terms of the overall number of breeding pairs they support” (Donald and Vickery, 2000). In BAMBU, land uses are not changing as much as in GRAS and SEDG, and therefore the population of adult skylarks is relatively stable. Without subsidies, as is the case in GRAS, land uses change according to commodity price fluctuations, and the land is managed intensively. This has a negative effect on skylark numbers since, on average, these numbers are the lowest compared with the other scenarios. Economic liberalisation therefore brings uncertainty for the viability of farmland bird populations since impacts are dependent on market forces rather than on policy intervention. In SEDG, extensive regimes and grass margins, which are beneficial to skylarks, are encouraged by substantial environmental payments and one would expect an increase in the population of skylarks. However, while the number of skylarks is the highest until 2035 compared with the other scenarios, a sharp decrease was observed afterwards that can be explained by the large expansion of bioenergy cropping occurring in this scenario.

Other simulation studies based on LUCC scenarios have shown the negative impact of bioenergy crops on wildlife at different spatial levels (Eggers et al., 2009; Gevers et al., 2011). In the latter study, an individual based model of skylark was used and the effect of land use scenarios was analysed. Gevers et al. found that skylark numbers were affected by the loss of crop heterogeneity when more than 13% of the land was replaced with maize, but it was also largely explained by the loss of set-aside replaced with these crops. In this study, static land use scenarios were used that did not simulate explicitly any possible lag effect that might occur in real world situations (Liu et al., 2007). We found that the negative effect of bioenergy production on skylark abundance occurred at different times in SEDG and GRAS. Two conclusions can be drawn from this observation. First, since the same area grown with miscanthus produces less energy in SEDG than in GRAS, due to the difference in yield performance, the amount of bioenergy becomes a poor indicator for assessing the impact on skylarks under a given renewable energy target as opposed to an area. Second, the low production of food energy in SEDG could also increase risks for the skylark population, despite the negative relationship found in Section 3.1. This indicates that a possible minimum threshold of food production as well as a maximum proportion of land converted to bioenergy crops are required to sustain skylark populations.

4.3 Importance of farmer heterogeneous decision making on ecosystem services delivery

The crop mosaic, intensity pressures and provision of ecosystem services in a landscape arise from the decisions of individual farmers. The proportion of farmer behavioural types in the Lunan catchment had an effect on the provision of food, bioenergy and on skylark abundance. There was however a dominant effect of the way profit-oriented farmers manage their farms in both BAMBU and GRAS, neutralising the positive environmental outcomes expected from other farmer types. The profit-oriented farmers are the most represented in the population of farmers (38%) and they favour the economic viability of the business over the enhancement of habitats for farmland birds (Chapters 2 and 3). In SEDG, the aggregate effect of heterogeneous farmer decision-making leads to higher skylark abundance than would be expected in simulations with exclusive farm types. This is possibly a result of the combination of high uptake of agri-environmental measures and extensive regimes up to 2025, and of a variety of farming objectives, which have a cumulative beneficial effect on skylarks; as opposed to BAMBU and GRAS where production and intensification dominate. In Chapter 4 (section 4.1), the consequences of the SEDG scenario on LUCC and management styles were greatly influenced by farmers' environmental and social values. Therefore, farmer (positive) values for the environment, when they are encouraged appropriately, are important to ensure skylark abundance and probably other ecologically-related aspects of the landscape.

Nevertheless, a positive attitude towards birds and socio-environmental objectives do not always benefit skylarks. For instance, bioenergy crops, which scored the highest for the environmental attribute in the model (i.e. do not require large amounts of nitrogen and provide a winter cover against soil erosion (see Chapter 4)), were applied by the multifunctionalist farmers to a large area because they wish to maximise environmental benefits over the farm, but had a deleterious effect on skylarks. This highlights the importance of appropriate information on the ecological risks associated with bioenergy cropping, which are advertised as environmentally-friendly.

4.4 Reflection on the approach

In this version of the model, farmers chose regimes as a function of their economic, environmental and social values. These values were computed using a simple scoring system already used by farmers for integrated farming (see Chapter 4 section 2.2.2). However, the scores are static over time and do not consider bi-directional feedbacks (see Figure 5.2) that could emerge from the IBM and impel farmer agents to re-consider their choices. It could be particularly relevant to experiment with the efficiency of innovative agri-environmental schemes such as ecosystem services payment-by-results, and adaptive co-management (Olsson et al., 2004; Goldman et al., 2007; Schwarz et al., 2008; Polasky et al., 2011). However, this would require additional data to be collected and more computational work. For example, the uptake and outcomes of per-clutch payments (Verhulst et al., 2007) or sward height measures (SNH, 2005) could be explored, but would necessitate the estimation of the utility of an attribute of decisions specific to bird impacts; especially since the importance of farmer attitudes and preferences for bird protection were shown to be positively associated with the uptake of higher level agri-environmental measures that target this issue (Swagemakers et al., 2009; Chapter 2). Simultaneously, the characterisation of alternative regimes as input to the model could be improved by including measures such as skylark plots and conservation tillage, which have proven valuable for increasing skylark breeding success (Field et al., 2007; Morris et al., 2007).

The model presented here has some limitations in terms of predictability and concept. If the model were fully predictive, the ABM/IBM integration could be used to answer specific questions about assigning proportions and combinations of land uses to maintain ecosystem services. The first issue to consider is the lack of spatial diffusion by skylarks to areas outside the case study, which can lead to biased interpretation on outcomes. The overall decrease in fledgling numbers could be an effect of the population equilibrium state; e.g. when the number of adults increases, less fledglings are produced. However, from 2040 onwards both the number of adults and fledglings decreases. Likewise, it has been found that as the territory density of the overall landscape increases, with a large area being planted with cereals, the size of territory shrinks resulting in lower reproductive success (Both and Visser, 2003). This trend implies the presence of an ecological trap, which often leads to population extinction (Battin, 2004), possibly explaining why the number of skylarks decreases after 2040 in all scenarios. However, in this model, the environment has closed boundaries, which does not allow the population to diffuse to surrounding landscapes. This leads to individual skylarks using the landscape to its maximum carrying capacity, establishing nests in sub-optimal conditions (e.g. use of habitat with minimum and maximum vegetation height). Secondly, food availability to skylark was not explicitly modelled and this could have resulted in an overestimation of the number of skylarks, especially in the economic liberalisation scenario, where intensive management reduce significantly the presence of invertebrates for young skylarks (Topping et al., 2005).

5. Conclusion

We have shown that the viability of the local population of skylarks, which has cultural importance to the farming community (Chapter 2), is intrinsically related to the landscape level arrangement of crop types and management styles, themselves decided by individual farmers who hold differing values for the sustainability principles. Economic liberalisation is not a good option for sustaining farmland birds since it implies most farmers to produce intensively in accordance with market signals and to abandon agri-environmental measures. Farmers who have environmental objectives play an important role in the preservation of farmland birds, but this requires substantial reward, especially if other policy goals have to be met (food security and bioenergy target). For that reason, single ecosystem services should not be assessed and targeted in isolation, and careful information should be passed to farmers on the possible trade-offs that exist between services, e.g. negative effect of large scale cultivation of bioenergy crops on skylarks. The formulation of policies should strategically take account of trade-offs between ecosystem service indicators, as proposed by Haughton et al. (2009) and by the European Environmental Agency (EEA, 2007), but in a dynamic manner, and should, we argue, also include farmer heterogeneity in decision-making. This could be achieved through collaborative plans at the scale of several farm units. Each decision maker within this spatial scale would have different functions depending on their interests, skills and other objectives. An alternative implies the collaboration of farmers with similar goals to achieve targets that are realizable at larger scales than the farm and in a complementary manner (Pelosi et al., 2010).

Chapter 6

Synthesis and further research needs

1. Synthesis

1.1 Novelty of the research

Intensive arable areas provide a number of ecosystem services essential to human welfare, but are subject to constant change due to external pressures. At the centre of these processes, the farmers are the decisive agents of land use change and the consequences it brings. This thesis emphasizes farmer decision making as a driver of Land Use and Cover Change (LUCC) and its impacts on the sustainability of farming systems. Farming systems are a good example of socio-ecological frameworks where the interrelationships between dynamic processes are intrinsically centred on human behaviour. These processes act at different spatio-temporal scales: higher level factors such as climate, market and policies, influence land managers in their decisions by phenomena of adaptation, mainly to survive financially but also to answer specific objectives alongside perceptions of issues. At the local level, similar biophysical characteristics and cultural habits create opportunities for researchers to explore the internal and complex processes explaining decisions on farm strategies. The latter have impacts on the sustainability of the system, on land use and cover change and on the provision of ecosystem services, for which an improved understanding and anticipation in uncertain futures are necessary to insure sustainability in intensive arable areas. This thesis is an attempt to answer these challenges by using an innovative integrated approach.

The initial literature review in Chapter 1 analysed the general context of farming areas, in particular intensive arable production, and identified gaps in land use-related studies. A number of conceptual issues need to be addressed and are essential for understanding the processes of LUCC as a result of the dynamics of complex socio-ecological systems, namely:

- Complex human behaviour
- Empirical information
- Spatio-temporal dynamics
- Scenario testing
- Model coupling/integration

The research carried out in Chapter 2 permitted to identify the main aspects of farmer decision making (i.e. financial, moral) that should be considered in the generation of a farmer typology. Given this information, a typology was developed in Chapter 3, which was used to populate the ABM with farmer agents. The different farmer profiles were investigated in details in this chapter, uncovering specific needs, motivations and knowledge. In addition, the information gathered about decision-making process (in Chapter 2) and its heterogeneity (in Chapter 3) was used to develop the conceptual framework to build the ABM in Chapters 4 and 5. The ABM/IBM presented in Chapter 5 was only an advanced version of the ABM used in Chapter 4. The findings of Chapter 4 permitted to have a better understanding of the underlying effects of farmer heterogeneity on the provision of ecosystem services derived from the simulations computed in Chapter 5.

Because the concept of socio-ecological system is relatively new, this thesis is aimed towards demonstrating the usefulness of an improved knowledge and modelling of farmer decision making in sustainable land-related research and policies. The synthesis section is formulated to answer the objectives 1, 2 and 3 stated in Chapter 1, and is followed by a section enumerating the policy recommendations derived from the findings (Objective 4). Finally, the issues and limitations of the approach are discussed and solutions are proposed for further research.

1.2 Farmers decision making, land use change and ecosystem services

1.2.1 From psycho-social and economic theories to a conceptual model of LUCC

> → *Objective 1: Understand how farmer decision making contributes to the processes of LUCC and land management in intensive arable areas*

To conceptualise the decision making model and inform it empirically, data were collected for the case study to: 1/ provide a general understanding of farmer attitudes, objectives and intentions in an intensive arable catchment, 2/ generate a typology of farmers based on these attitudes and objectives, and 3/ estimate the decision making model using a choice experiment approach.

Chapter 2 allowed a primary understanding of the internal values that underlie farmer decisions on farm strategy. Psycho-social theories, such as the theory of reasoned action (Fishbein and Ajzen, 1975), define attitudes as one of the causal factors of behavioural change. This can advance the modelling of human decision making in complex systems (Evans et al., 2006) because farmers base their decisions on the perceptions they have towards the system, assuming they have an incomplete knowledge of them (Janssen, 2005).

Farmers in the Lunan were concerned with the viability of the farm, the social acceptance and the moral responsibility for ecological issues. Despite most farmers expressing willingness to pursue the same strategies in the future, the majority intended to become more environmentally-friendly, e.g. decrease the use of agro-chemicals and apply winter cover crops. These intentions were found to be correlated with attitudes and objectives, and demonstrate the significance of considering individual values in models of decision making to understand and anticipate farmer reactions in different contexts.

As a means to simplify the modelling of individual farmer agents, a typology was generated in Chapter 3 using statistical techniques such as principal component analysis on attitudes and objective-based questionnaire statements, and hierarchical clustering based on the selected components. Four dominant farmer types were described: profit-oriented, multifunctionalists, traditionalists and hobbyists. These types did not differ significantly in terms of farmer characteristics or farm structure, but were principally defined by their objectives and attitudes towards the environment and the societal demands. Profit-oriented farmers aim to maximise profit and do not hold a strong moral value for the ecological or social aspects of farming. The multifunctionalists are willing to consider all these aspects within farm strategies but the financial aspect is highly important. Traditionalist farmers are the most conservative, although they intend to become more environmentally friendly in their practices. The hobbyist type has very strong positive attitudes towards environmental and social issues, and shows interest for developing non-farming activities, e.g. agritourism.

It would have been possible to develop a probabilistic model of decision making based on questionnaire answers (e.g. decision tree), however, this approach is not sufficient in explaining and simulating the reactions of individual farmers under various future socio-economic contexts, for which no data is available. An optimisation approach based on “subjective” utility was therefore associated with the farmer typology. The utility function was disaggregated into the three sustainable principles; economic viability, environmental quality and social welfare, to determine *ad hoc* farmer reactions to a problem and to simulate adaptability in human behaviour. The preferences for these three attributes of decisions were estimated as partial utilities, which represent the satisfaction, or well-being, of the decision makers.

Preference structures for sustainable trade-offs translated well with the perception-based typology as well as innovative and conservative behaviour (Chapter 4, section 2.2.1). Two different structures can yield similar outcomes, i.e. traditionalist and profit-oriented farmers, but the reasons are intrinsically different. This has importance for analysing and discussing results of simulations, and for deriving more specific policy recommendations.

The use of partial utilities for sustainable attributes of decisions necessitated the valuation of alternatives to let the farmer agents select autonomously a regime in accordance with their preferences. A scoring system of indicators stemmed from the choice-based conjoint and adapted from DEFRA’s integrated management guidance was used for the valuation of alternative regimes. These indicators are the most likely to represent what farmers consider when making decisions on their farm strategies. Because the analysis of past time-series data from census surveys (Chapter 3) demonstrated a stronger influence of financial aspects on actual behaviour, the economic component had a higher weight in the utility function compared with environmental and social components.

1.2.2 Heterogeneity in decision making and reactions to socio-economic contexts

> → *Objective 2: Analyse how heterogeneity in farmer decision making affects the spatio-temporal patterns of LUCC under various socio-economic contexts using an Agent-Based Model*

The agent-based model represents the LUCC dynamics as an emergent phenomena derived from heterogeneity in decision making. The proportion of the different farmer types generated in Chapter 3 was used to distribute individual farmer agents within real farm boundaries of the catchment GIS-based representation. Three ALARM scenarios, BAMBU, GRAS and SEDG, were utilised and the farm strategies chosen by farmer type were tested in Chapter 4. GRAS represents an economic liberalisation context, where environmental and social issues are of secondary importance to society. Prices decrease due to technological improvement of yield performance, and both direct payments and agri-environmental funds are abandoned. SEDG is sustainability-focused, with subsequent policy instruments to encourage socio-environmental actions. BAMBU is comparatively intermediate and represents today's context, with future shifts of funds from direct payments to agri-environmental schemes, which is arguably more reflective of the proposed reforms of the Common Agricultural Policy (CAP).

The simulations of farmer decision making in different contexts showed that land use types and management styles did not differ significantly between farmer types, although the share of these choices within the farm land varied. The profit-oriented farmers demonstrated higher adaptability to financial incentives (whether direct payments or market prices), but failed to maximise their profit in the SEDG scenario. Multifunctionalists established a balance of multiple objectives and adapted to the socio-economic context, but in GRAS and SEDG their choices generated a loss of profit. Traditionalist farmers applied practices, under these scenarios, that preserve and enhance the socio-ecological attributes of farm landscapes without financial support or application of innovative practices. This is the only type to have obtained a positive utility in SEDG. All farmers traded off the economic, environmental and social attributes of decisions, but the financial aspect were dominant, especially in BAMBU and GRAS. There was in general a stronger influence of direct payments in

BAMBU, and of price signals in GRAS, on land uses and management choices than of the influence on internal values, unless this was encouraged with substantial financial incentives (in SEDG).

In BAMBU, direct payments were maintained and the land use cover was unlikely to change because farmers find a relative balance between economic, environmental and social attributes of the farm strategy. In GRAS, land uses and management styles fluctuated in response to market signals. Economic liberalisation led to the diversification of land uses and the increasing effect of technological improvement on yield. However, the decreasing level of subsidy for agri-environmental actions limited the scale of application in GRAS. In SEDG, the implementation of environmentally-friendly management was facilitated by subsidies and influenced by high input prices. Because of this, farmers maximised an aspect of the environmental and social definition of regimes. Multifunctionalist farmers were concerned with the level of nitrogen application and, therefore, switched grass margins and extensive management for the more viable and subsidised bioenergy crops by 2050. The profit-oriented farmers maximised the cover aspect through winter cropping and extensified production because of high input prices. The traditionalists maintained intensive regimes but maximised the diversity of crop rotations and the social aspects, i.e. tradition and access to green space.

In all scenarios, the loss of grassland for growing cereal crops raised concerns for environmental problems and the provision of ecosystem services, and limits the opportunities for applying more agri-environmental options that are easier in mixed farming. Bioenergy cropping did not develop in BAMBU since farmers continued the practices attached with direct payments. In GRAS, the rise of bioenergy production was initiated towards 2050 with yield performance allowing its economic viability. In SEDG, because subsidies were proposed to encourage bioenergy production, the share of land possibly exceeded environmental and social sustainability. These issues were explored in Chapter 5, which is summarised in the following section.

1.2.3 Effects of heterogeneous farmer decisions on the provision of ecosystem services

→ *Objective 3: Explore how the provision of ecosystem services is affected by heterogeneous farmer behaviour*

The integrated ABM/IBM presented in Chapter 5 allowed the study of ecosystem services provision at landscape level emerging from individual valuation of sustainability. The aggregate, or emergent, effect of heterogeneous farmer decisions was assessed on a number of ecosystem services, essentially the provisioning (food and bioenergy) and cultural (skylarks). This had two main aims: 1/ to assess the effects of farm strategies on ecosystem services delivery at a detailed level of resolution, and 2/ to measure the importance of farmers values and the proportion of farmer types on the provision of ecosystem services under different scenarios. The simulation of decision making and the impacts it will have on ecosystem services and functions is of great importance to identifying the challenges the catchment will face in terms of land use dynamics in changing and uncertain circumstances.

The aggregate effect of farmer decision making at the landscape level showed the combination of ecosystem services delivery, for which the levels vary in each scenario. The BAMBU scenario showed the highest benefit to skylarks in the long-term, but food supply was medium and the bioenergy produced was low. Due to the financial stability offered by direct payments, land use and management did not vary in this scenario, possibly explaining the relatively stable population of skylarks observed. In GRAS, the production of food dominated, with a medium production of bioenergy, but, as expected, skylark numbers were lower, on average, than in the other scenarios. The latter was possibly due to the poor uptake of AES and highly intensive management. The farm strategies applied by the profit-oriented farmers had a dominant effect at landscape level in BAMBU and GRAS, neutralising the positive environmental outcomes expected from more environmentally-friendly farmers (multifunctionalists and traditionalists). The positive effect of the SEDG scenario on average skylark numbers also illustrated the importance of farmer attitudes and objectives towards the environment if significant financial rewards are proposed. However, an increased production of bioenergy by 2050 created loss of suitable habitats for breeding skylarks and thus proved incompatible with the agri-environmental objectives.

1.3 Policy recommendations

> → *Objective 4: How to improve land-related policies to support sustainability in intensive arable areas?*

Although LUCC has direct consequences on the provision of ecosystem services, policies are crucial to ensure land use occurs in a sustainable manner and responds to the demand for supporting, provisioning and cultural services. Each chapter brought a number of recommendations for improving the effectiveness of policy formulation to support sustainability in intensive arable areas, in particular by taking into account:

- Farmer attitudes and multiple objectives in decision making
- Heterogeneity within local populations of farmers
- Dynamic transitions of land uses and management emerging from individual decisions
- Trade-offs in the provision of ecosystem services

1.3.1 Sustainable policy intervention

While the Common Agricultural Policy envisions a "greening" of production-related payments, the market liberalisation proposed for future reforms will create uncertainties for the sustainability of arable farming systems. If market forces become the most powerful pressures on farmer decisions, the ecological and social consequences will be difficult to control. The loss of set-aside has led to a shortfall in the provision of environmental benefits, and the removal of direct payments will also cut the benefits brought by cross-compliance. This is why a change in behaviour and participation in agri-environmental schemes are the solutions to secure the sustainability of future farming landscapes. However, the intention to participate in AES was low in the Lunan catchment, despite a general concern for both moral and utilitarian environmental issues. A number of constraints to participation were derived from the analysis of questionnaire answers:

- Misunderstanding of ecological requirements for species habitats within and around the farm,

- Lack of information on the current state of biodiversity and other socio-environmental issues,
- Insufficient financial rewards based only on compensation costs associated with the measures,
- Scheme inflexibility, e.g. length of contract, lack of fit within management.

From the results in Chapter 2, it became apparent that farmers with strong values for the environment would respond positively to schemes with strong messages emphasising a single objective, i.e. enhancement of farmland bird habitats. This is particularly true since the goal to achieve is clear and satisfying to the decision maker. However, because this requires more involvement from the farmer, the payments could be increased so that actions are rewarded and not only "compensated". Consequently, farmers would have the responsibility to deliver public goods and receive the approbation of a larger community that encompasses other farmers and the general public. Social recognition was shown to be highly important for most farmers. If farmers were trained and encouraged to self-assess the environmental and social outcomes of their practices, they would certainly start to compare themselves and improve their stewardship skills. This is possible by informing farmers on environmental and social issues and by demonstrating the effects of farm strategies on the provision of ecosystem services. The SRDP 2007-2013 proposed targeted schemes that are region specific (Rural Priorities) but this was criticised for lacking control over the scale of delivery of options (farm, local, regional) and for being highly inflexible and bureaucratic (RSPB, 2011).

The problem currently is that policy designed to limit the negative impact of land uses and management on ecosystems are addressed at regional level (e.g. NUTS), which considers that similar biophysical conditions are sufficient to explain similar needs for farmers. By taking into account the heterogeneity in decision making, it is possible to further refine the design of policy in order to encourage a maximum number of participants. Enabling the fulfilment of a variety of objectives and knowing the proportion of farmer types within a landscape is essential to initiate a change in behaviour and to plan policy instruments. The network of relations (from European policy to local "advertisement" and environmental benefits on the ground) can act as a crossing point between action and perception (van Herzele et al., 2011). Improving the advisory system directed at specific farmers is key to attitudinal and behavioural changes (Brodt et al., 2006; Sutherland et al., 2011). Table C.1 in

Appendix C displays the frequency with which farmers seek information and the themes they look for. To be more effective, the information on sustainable farming practices and AES must be directed to suit varied attitudes, objectives and needs. Different approaches, from individualistic to more collective ones, should be considered to deliver information successfully. The message given should emphasize all aspects of decision making so that it appeals to a broad range of land holders. For instance, financial consequences, landscape appearance, social cost, and environmental outcomes have to be addressed. Figure 6.1 addresses the recommendations brought up by this study within the 4 E's framework of the sustainable development diamond (DEFRA, 2008).

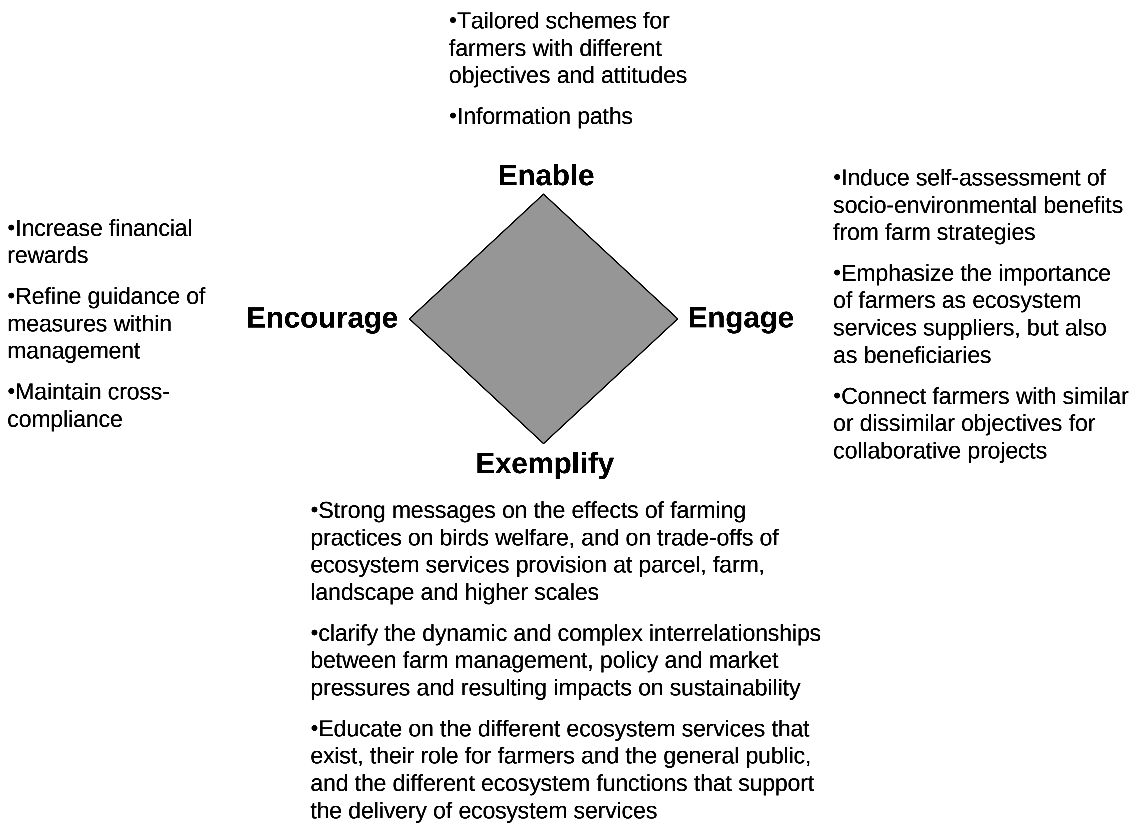

Figure 6.1 – A re-assessment of the Sustainable Development Diamond suggested by DEFRA (2008)

1.3.2 A common objective for the CAP

According to the EU, the CAP is now concerned with three main objectives: food security, climate change adaptation and mitigation, and preservation of biodiversity and other environmental aspects. These objectives have to be reflected upon a sustainability framework. However, if each objective is considered in isolation, an unbalanced provision of ecosystem services is likely to happen, destabilising the principles of sustainability at all geographical levels. Land uses and management take place at the local level and are direct drivers of ecosystem services provision, which is affected at the local and also at larger scales (Cumming et al., 2012). Farmers have generally an “egocentric” view of sustainability, while policy must address these local as well as global scale impacts. Carefully structured information to farmers could reverse this “egocentric” attitude and re-align positive attitudes towards more extrinsic values. The analysis in Chapter 5 has shown how the consideration of ecosystem services trade-offs in a dynamic model of LUCC can benefit the assessment of simulated LUCC scenarios and the design of policy. Attention given to the heterogeneity of farmer internal values and preferences for the design of schemes could potentially answer issues in ecosystem services trade-offs. Accordingly, collaborative and outcome-based schemes can be drawn that satisfy a variety of interests, skills and other objectives and bring environmental benefits at a larger spatial scale than the parcel or holding-level. In addition, the scale at which the CAP objectives are considered must be addressed, in particular the proportion of land attributed to each objective. Again, the heterogeneity in farmer decision making plays a role in the appraisal of land share in the future.

2. Limitations of the approach and further research needs

To improve the practical use of the model outcomes for sustainability assessment and policy analysis, futher development is required such as uncertainty (sensitivity) analysis and validation. Focus groups with stakeholders and participatory approaches could be used to validate the farmer decision making model.

Developing an ABM of a complex socio-ecological system is an art as much as a science (Bonabeau, 2002; An, 2011). It is therefore difficult to determine the appropriate levels of complexity and sophistication needed to answer particular research questions. However, the work carried out in this thesis has allowed the identification of lacuna and limitations in predictability and concept. These limitations are enumerated in the following sections and are accompanied by potential solutions for improving the methodology.

2.1 Characterisation of agents

The collection of social data presented some problems where important information could have been lost or misinterpreted. Even with random sampling of respondents, questionnaire answers are always restricted to people who agree to participate, creating response bias and possibly ignoring potential farmer types. In the same manner, if questions are related to sensitive subjects such as environmental issues, respondents tend to aspire towards “social desirability” (Kaiser et al., 1999; Maguire, 2009).

In addition, due to cost limitations, surveys are usually carried out at one point in time so it is not appropriate to represent temporal variation and the changes in attitudes (Robinson et al., 2007). The use of past time-series from census data to validate and refine perception-based typologies of farmers has been shown relevant to this matter (Chapter 3). However, there are uncertainties about farmer reactions to future and unknown conditions. Since the repetition of social surveys is not always achievable, this issue has to be conceptually resolved. First researchers need to determine whether the farmers switch type or if the internal values and preference structures defining a type are altered during the course of their life and in different context. Janssen and de Vries (1998) opted for the first theory and used a threshold value to change the proportion of agent types according to changing “world views”. This threshold value represents the effect of surprise when observed outcomes differ from expected ones. The evolutionary modelling approach allows a better alignment of agent perceptions and behaviour with the observation of global social change that defines a socio-economic scenario. For instance, in the SEDG scenario, multifunctionalist farmers would be more numerous than the profit-oriented. In the same manner, a temporal deviation in farmer types could occur at different stages of the life cycle (Ondersteijn et al., 2003), e.g. profit-oriented farmers would become traditionalist at a certain age. Decisions to exit farming and transaction or abandonment of land should be modelled explicitly over time since it could have impacts on the sustainability of arable areas, e.g. larger polarisation between large and small farms (Lobley and Butler, 2010), loss of habitats to specialist species (IEEP, 2007). Probabilistic methods could be used based on questionnaire answers (see "additional information" in Appendix D).

The heterogeneity in decision making was represented by an average preference structure specific to farmer types. Brown and Robinson (2006) demonstrated that a lack of variability within agent types had less influence on simulation outcomes. They suggest using distributions from mean and standard deviation of preferences for clusters of agents. This method was also used by Valbuena et al. (2010 a,b), and could be easily explored with the current state of the model used in this thesis.

2.2 Farmer decision making

The utility function was disaggregated into sustainable principles, i.e. economic, environmental and social, although other attributes have importance in decisions. For instance, the work load associated with farming practices, and the risk associated with it. The choice-based conjoint questionnaire included these additional factors (see Appendix D) and could be added within the utility function.
Spatially-explicit behaviour could be implemented if a different type-specific utility function was used for land of different quality. In appendix E, the results of the choice-based conjoint were analysed for marginal and good quality land. By applying a map of land capability[26] to the GIS-based catchment data, it is possible to link farmer decisions to bio-physical characteristics (Appendix I, Figure I.2). In general, the farmers preferred to apply agri-environmental measures and non-food crops to marginal land. These outcomes could improve the modelling of LUCC, bring further insight into where ecosystem services would be delivered and give a spatial emphasis for scheme design and needs (Evans et al., 2006).

The analysis of census data in Chapter 3 has shown that the financial aspect of decisions was dominant over other environmental and social objectives. For that reason, the scoring system of the economic attribute was not bounded compared to the environmental and social ones. This can have important consequences on the

[26] See footnote 6, page 52.

simulation outcomes, i.e. choice of land use and management. A sensitivity analysis could be carried out to evaluate the effect of changing the scoring system "boundaries" of each attributes on farmer decisions, LUCC, and ecosystem services provision. On the other hand, different weights could be given to the three attributes in function of scenario narratives. For instance, it would have perhaps been more logical to assign more weight to the environmental attribute rather than the economic one in the SEDG scenario. However, changing the "boundaries" of attribute scores requires modifications in the design of the choice-based conjoint experiment. In the thesis, the economic attribute was represented by quantitative levels, i.e. -10%; 0; +10%, which can be unbderstood literally by the respondents, while the environmental and social attributes had qualitative ones, e.g. negative; neutral; positive. In order to "bound" the economic score similarly to the environmental and social scores, the economic attribute levels should also be defined qualitatively.

The set of indicators chosen to represent the environmental and social attributes of farming practices was limited to the modellers perceptions, even though indicators were selected as the most important and comprehensible aspects that farmers consider. In addition, these indicators are representative of local and "egocentric" values. Indeed, farmers place higher values on services they can directly access, i.e. the endowment effect (Lowenstein and Adler, 1995), do not necessitate additional managerial skills to produce (Cooke et al., 2009), and for which the existence is known (Swift et al., 2004). Therefore, a complete, and type-specific, definition of sustainability should be drawn with a larger set of indicators to vary the choices farmers make. First, the scale and variety of beneficiaries for which indicators are representative must be addressed in social surveys (Evans et al., 2002). Besides, more indicators could be added to the evaluation of regimes and this would expand the nature of decisions. For instance, new indicators such as impacts on bird habitats, which has been shown very important to farmers, and the emission of greenhouse gases from practices could have various level of influence on farmer decision-making. More research is therefore necessary to understand how farmers perceive sustainability and how it might impact on decisions. This could both improve the transparency of the model and have significant advantages in improving policy design to encourage farmer actions towards larger scale issues.

2.3 Integration and feedback mechanisms

The model presented in this study allowed the observation of the ‘cascade effect’ from high level factors, heterogeneous farmer behaviour, land use change and resulting impacts on the provision of ecosystem services. However, feedback loops exist and act constantly between the components of a socio-ecological system. For instance, if one knows how important are skylarks or the provision of bioenergy to a decision maker or group of decision makers, a learning process can be applied to induce the agent to reconsider their choices at the next time step. Hence, the evaluation of regimes becomes dynamic as opposed to the static scoring system used in the current version of the model. This would considerably improve the representation of socio-ecological interactions. In particular, it would assist the experimentation of innovative agri-environmental schemes such as ecosystem services payment-by-results, and adaptive co-management (Olsson et al., 2004; Goldman et al., 2007; Schwarz et al., 2008; Polasky et al., 2011). However, this requires the collection of additional data and more computational work. Simultaneously, the characterisation of alternative regimes inputted in the model could be improved by including measures such as skylark plots and conservation tillage, which have proven valuable for increasing skylark breeding success (Field et al., 2007; Morris et al., 2007).

The use of average data to parameterise the individual-based model of skylarks did not allow the representation of important bird-land use feedbacks that might be disturbed by farmer actions and climate change. For instance, climate change could influence the timing of farming operations (e.g. sowing, harvesting, cutting; Olesen et al., 2011) and the start of bird’s breeding season (Crick, 2004), which are fixed in the current version of the model. This will affect the reproduction of skylarks and will require modifications of agri-environmental measures. In the same manner, seasonal variations were observed in skylark crop-type specific territory densities due to vegetation structure (Appendix G). For this reason, the sub-model of vegetation growth could be improved to illustrate changes in vegetation structure affected by farming operations and climate change. Food availability for skylarks depends on management style and crop types (Benton et al., 2002) and could be implemented in further development of the model if data are available (see Topping et al., 2005).

The socio-ecological processes and integration of sub-models occurred at a high level of resolution, i.e. the parcel, which limits the valuation of indicators at this level, e.g. aesthetic and recreation values, and spatial diversity. A further step in developing this model is to include additional spatial features and to generate rules of behaviour with regard to this factor. Some work has been carried out during this thesis that could not be implemented in the model as a result of time constraint. The addition of a raster-based GIS layer to the spatially-explicit IACS data allows us to localise current forest patches, household, hedgerows and water bodies (Appendix I, Figure I.1). At the present stage of development, the model outcomes only presented temporal diversity rather than spatial, creating underlying issues for the assessment of LUCC and ecosystem services delivery, i.e. numbers of skylarks. The method for valuing regimes indicators should be relaxed so that farmer agents can assess the utility of regimes at parcel, farm and landscape levels.

2.4 Towards generalisation

The study of farmer values and decision making has highlighted the need for local and targeted actions in order to encourage a maximum number of farmers to participate in agri-environmental schemes. However, because policies are usually designed for regional or national level, one must ask if these findings can be directly usable for policy development. The author suggests that the conclusions made in this thesis are applicable to intensive arable areas in the UK. On one hand, the farmer typology that was generated in this study was relatively similar to typologies found in other intensive arable areas (e.g. Shucksmith, 1993; Davies and Hodge, 2007; Sutherland, 2011). The diversity of needs and motivations specific to these typologies could be addressed in further policy development. On the other hand, the biophysical and socio-economic processes simulated in the integrated ABM/IBM are common to these regions, at least at the national scale (policy, market and technology). For less intensive areas such as extensive/rough grasslands, the author proposes to conduct similar social surveys to identify differences in farmer perceptions and behaviour, and the degree at which external pressures impact on decision.

To increase the effectiveness of the ABM used in this study for the development of European level policy and land management options, the ABM must be applicable to other case studies and up-scaled. This presents a new conceptual and methodological challenge to generalise farmer types without losing complexity and heterogeneity (Audsley et al., 2006; Rindfuss et al., 2008; Rounsevell et al., 2012). The understanding of individual decisions at a high level of details, which was one of the aims of this thesis, is believed to be an essential exercise prior to generalisation and assessment of data collection (Parker et al., 2008; van Delden et al., 2011)[27].

More species could also be represented using individual-based model integration, with parameters specific to generic species with similar ecological requirements (e.g. Parrott and Kok, 2002). This would contribute to a better assessment of biodiversity level and the ecosystem functions it supports under different socio-economic and climate scenarios.

3. Concluding remarks

Intensive farming systems have been the focus of considerable study, in terms of understanding environmental and social impacts. The impact of decision-making is a further, more significant layer to explore and presents a significant challenge to integrating social systems within ecological assessments. However, in order to create change within these systems and to reflect societal desires in farming landscapes, it is essential to develop more modelling tools such as the one presented in this thesis and to design methods for geographically broader applications. This is an important element for research investigation.

This thesis intended to bring additional knowledge to farmer decision making and to integrate this information in complex model of land use change within socio-ecological farming systems. This constituted conceptual and methodological challenges, which were undertaken through analysis of empirical data collected for a specific case study. The consideration of heterogeneity in farmer behaviour and dynamic adaptability of agents to external pressures allows us to widen the current view on land use change and the environmental and social consequences associated with it.

[27] A paper is currently in preparation to address these issues by comparing and re-defining farmer types across different European and non-european countries (Belgium, Scotland and Switzerland).

Computer simulations using an agent-based model approach are powerful communication tools for stakeholders and the general public to understand the implications of future land use change. Hence, it can feed into the growing field of virtual landscape visualisation assessment. Indeed, the Lunan Catchment and results from this work are being used as the basis for presenting a 3D visualisation in conjunction with the Universities of Abertay and Edinburgh[28].

[28] See https://www.youtube.com/channel/UCuRVW78N1vdXVWm4a5oXqhQ (Developed by Christopher McCreadie)

Appendix A

Analysis of Census Data for the Lunan Catchment (1995-2007)

This is an initial analysis of June Agricultural Census (JAC) data collected for the whole 12 parishes that are included within the Lunan catchment. In total, the area is 347 hectares and comprises 350 farms. This assessment had permitted to gather information on what has been happening in the area in the last 13 years. For instance, while the area of owned and rented holding is relatively stable (Figure A.3), the area of crops and grass diminishes from 2003, after the decoupling of direct payment (Figure A.1). In term of agricultural activities, the main crop is cereal with an increase in winter-sown crops and a decrease in spring cropping towards 2007 (Figure A.4). The area cultivated for vegetables for human consumption and for bulbs and flowers had increased after decoupling (Figure A.7 and A.9). The area of grassland has remained relatively stable, although there was an increase in permanent grassland used for grazing (Figure A.8).

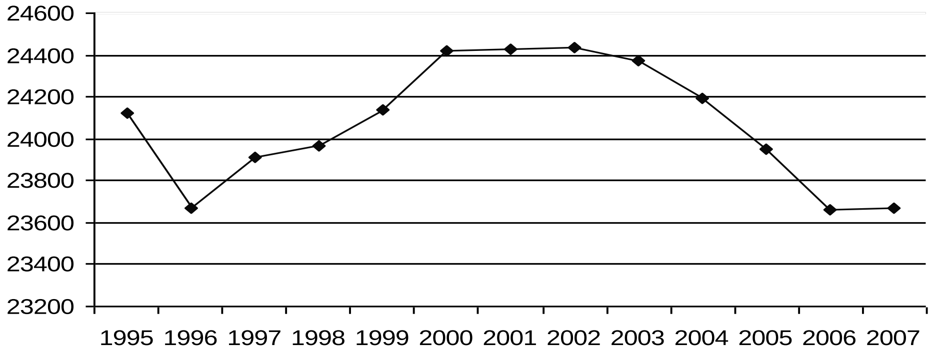

Figure A.1 - Total area of crops and grass in the Lunan (Ha)

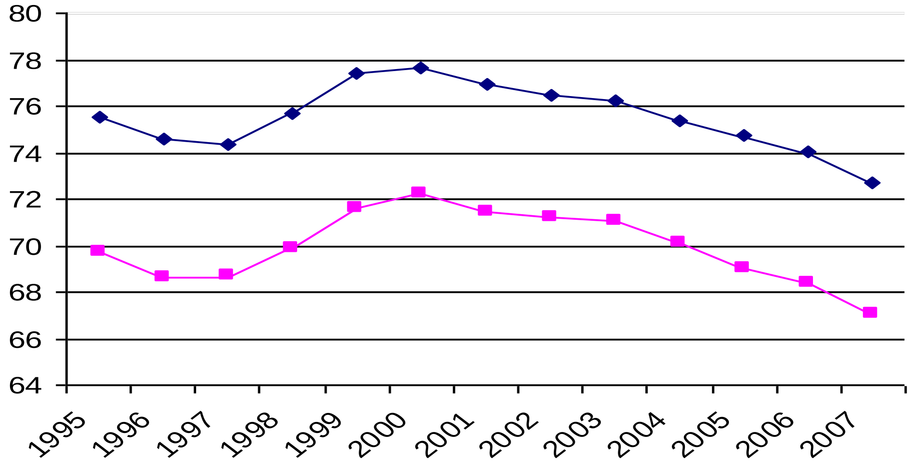

Figure A.2 - Average Holding size (in blue) and Managed area (in pink), (Ha)

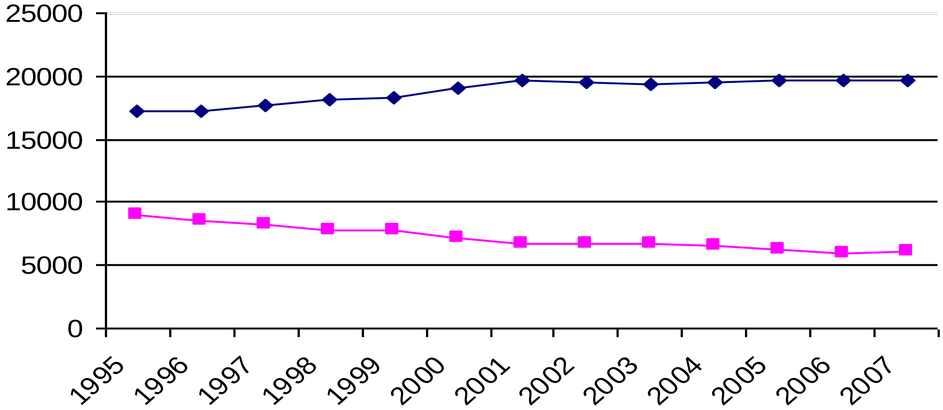

Figure A.3 - Total rented (in pink) and owned (in blue) area of holding (includes all types of agricultural and non-agricultural land), (Ha)

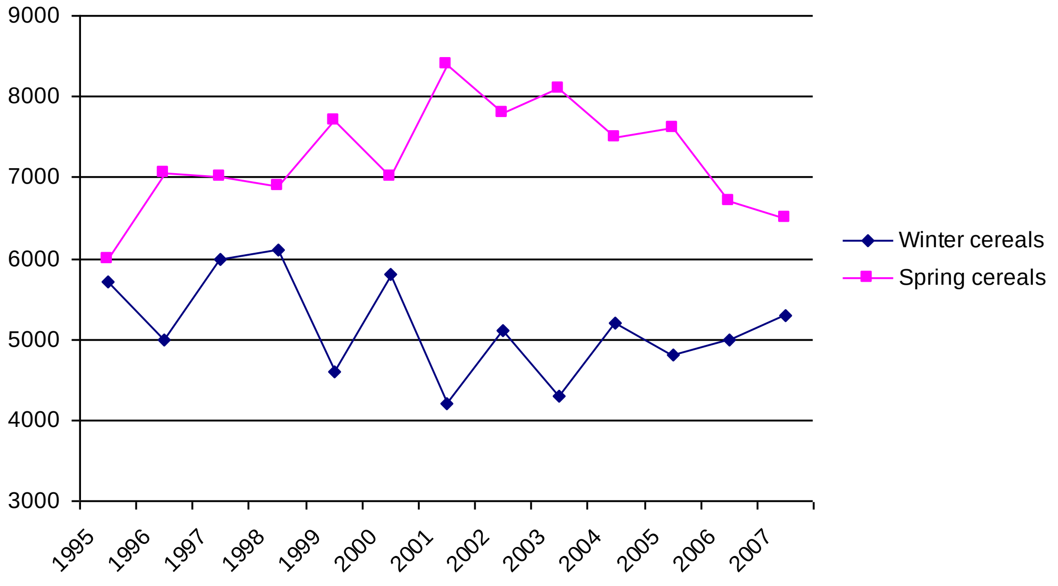

Figure A.4 - Total area of cereals, (Ha)

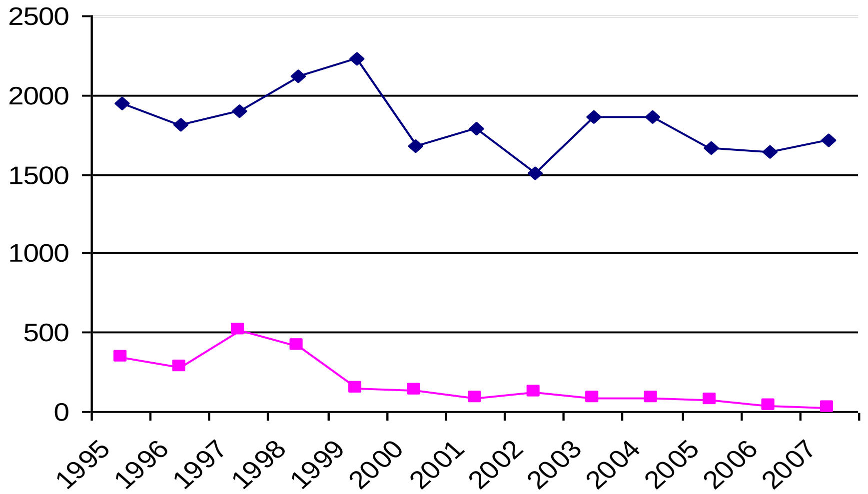

Figure A.5 - Total area of oilseed rape, winter-sown (in blue) and spring-sown (in pink), (Ha)

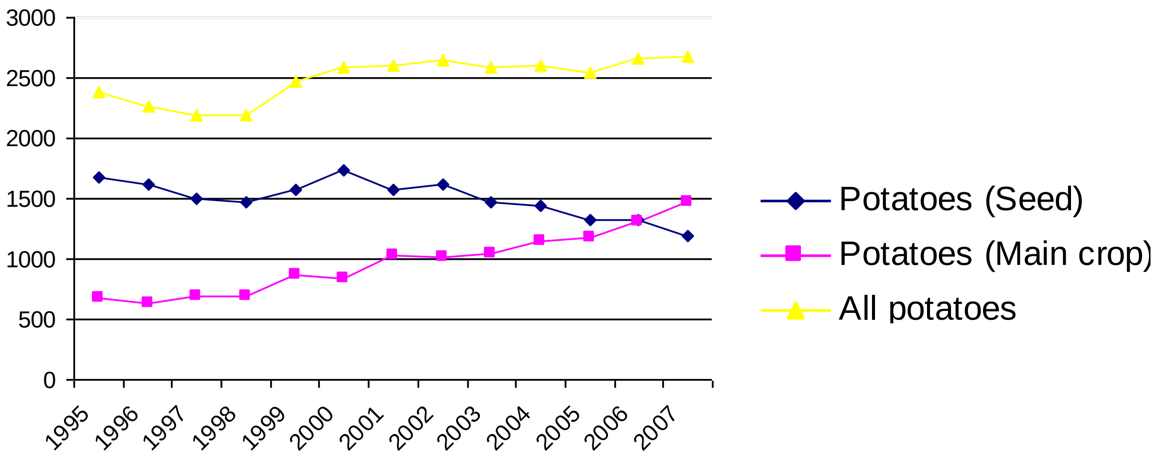

Figure A.6 – Total area of potatoes (Ha)

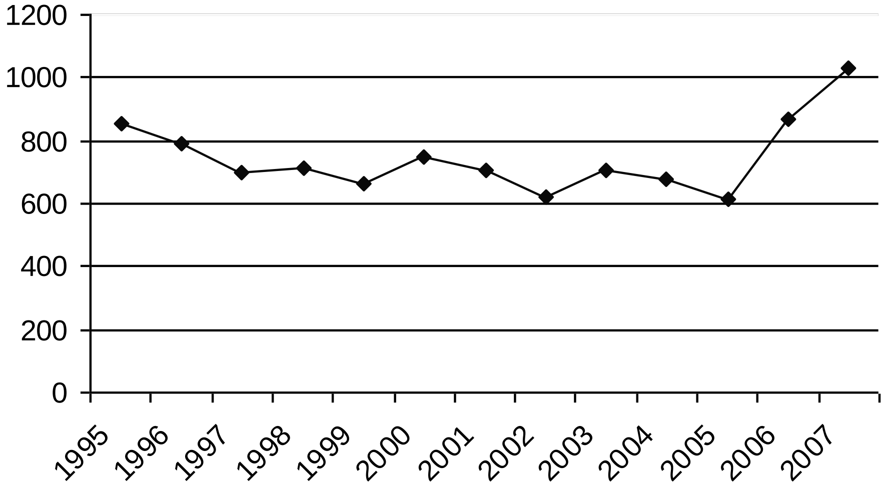

Figure A.7 - Total area of vegetable for human consumption (Ha). It includes beans, peas, turnips, Swedes, kale and cabbages

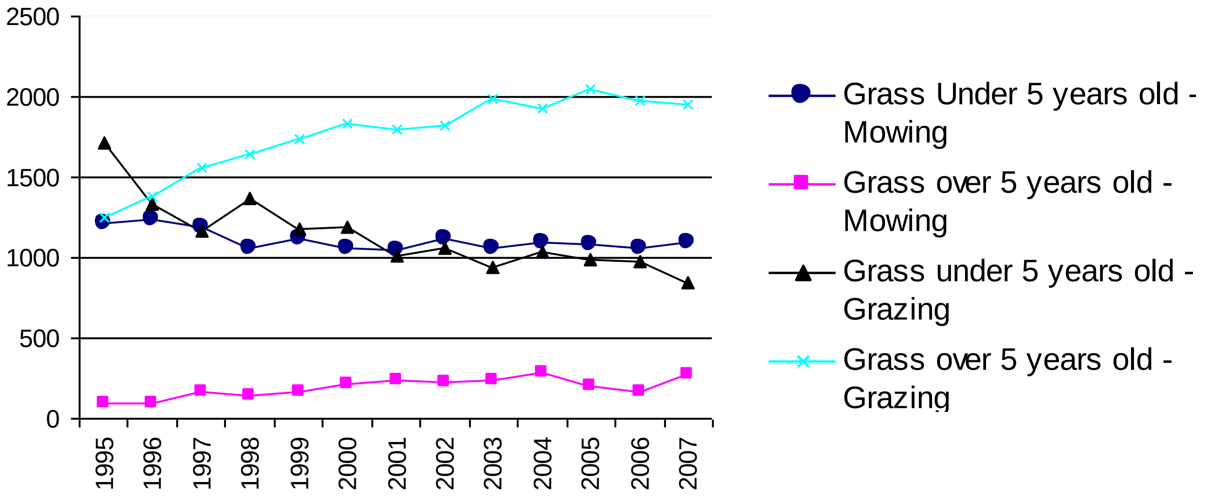

Figure A.8 - Total area of grassland (Ha)

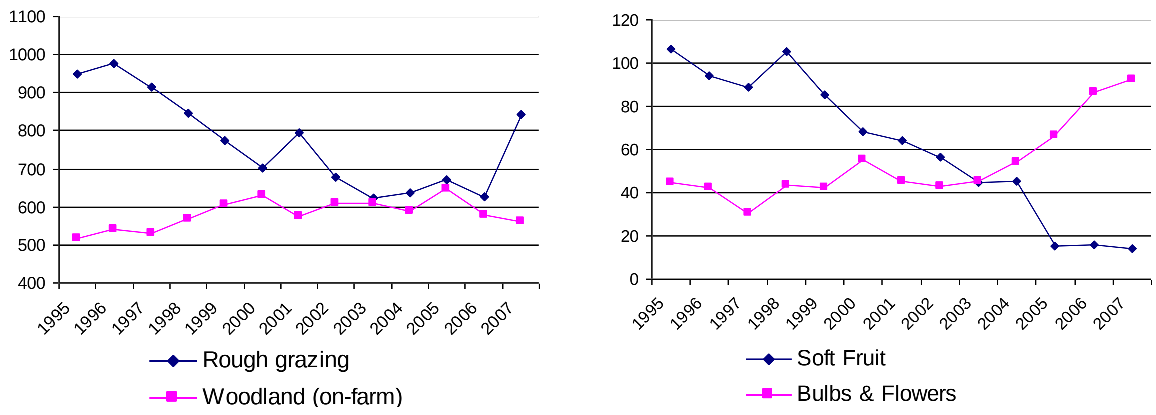

Figure A.9 - Other land uses (Ha)

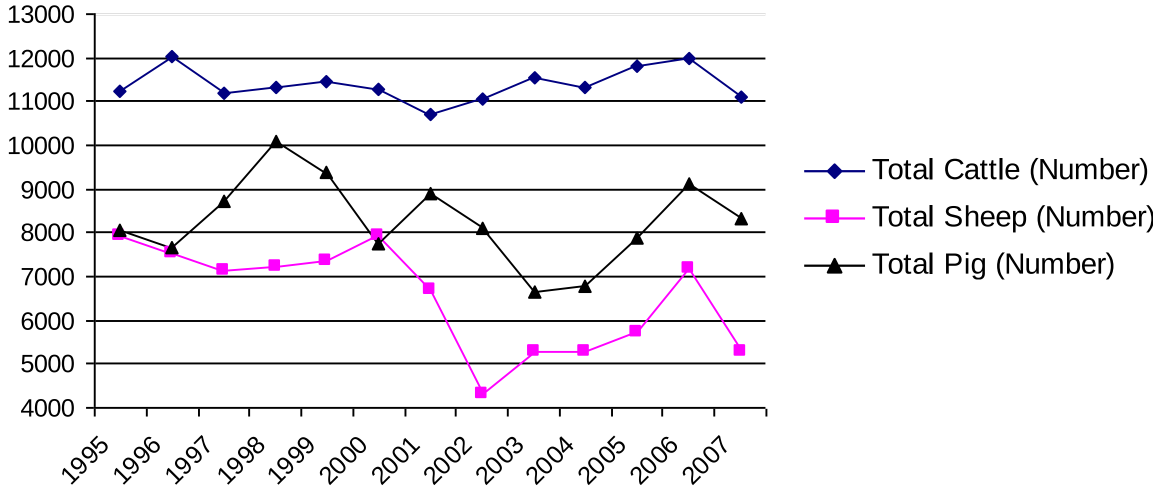

Figure A.10 - Livestock types and numbers (head)

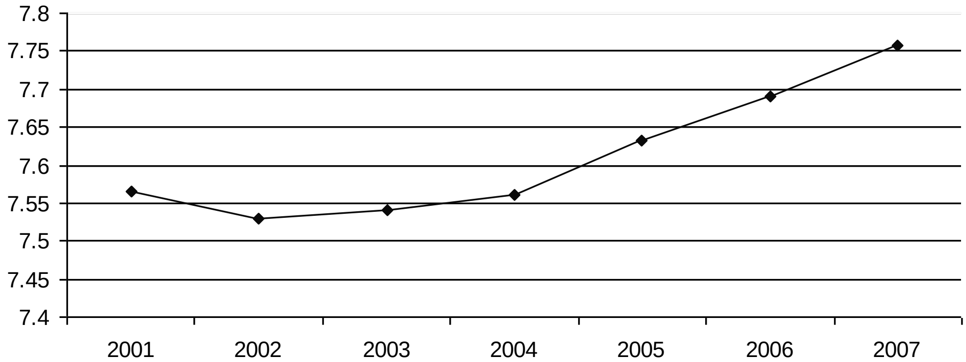

Figure A.11 - Average field size (Ha). Data from IACS 2001-2007

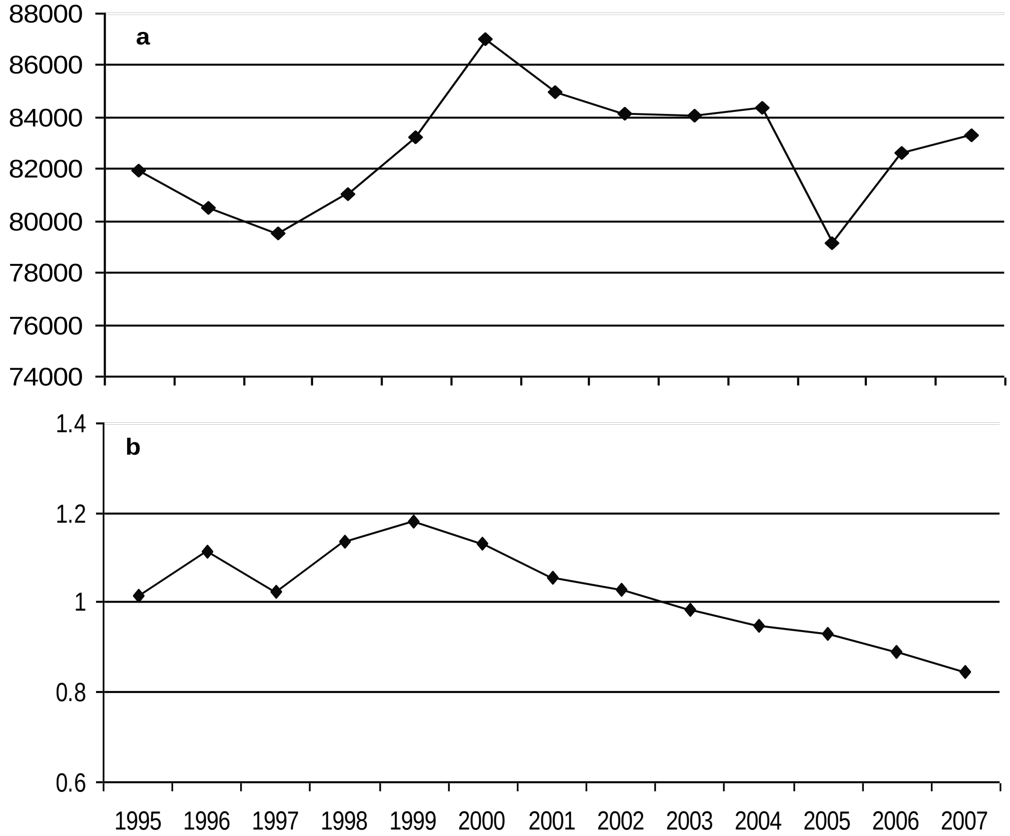

Figure A.12 - a. Average Calculated Standard Gross Margins (in £) and b. Average number of regular and casual staff

Appendix B
Phone Survey

The following questionnaire is the first phase of the social survey aiming at:

- determining farmers attitudes and goals with regards to farm strategies and land use change in the Lunan catchment,
- investigating farmers attitudes towards birds and their willingness to protect them,
- generating a typology of farmers based on attitudes and goals of farming,
- identifying the factors that drive to land use change (and adoption of agri-environmental schemes) in the Lunan,
- perceiving farmers view on the future of farming and how they react to it,
- assessing the demographical characteristics of farmers,
- defining the main attributes of decision making to consider in the second-phase choice-based conjoint survey.

The questionnaire is preceded by a cover letter that stipulates the confidentiality of the data collected and to establish the legitimacy of the survey according to the university regulations. The farmers wishing to participate in the survey were contacted through telephone during the summer 2009.

Dear sir or madam,

We at SAC are conducting research into farmer attitudes and opinions towards agriculture and biodiversity. We would therefore like to interview a range of people, like yourself, who manage or make decisions about how land is used.

We would like to pass your contact details to an independent research contractor so that they may call to make a telephone interview with you at a convenient time. **If you would rather we did NOT pass your details to the contractor, please complete and return the slip below in the enclosed pre-paid envelope.** We will then ensure that your contact details are not passed to the researchers and you would not be approached to participate in the study.

Please be assured that, if you are happy to be contacted, all responses will be treated in confidence and any information you provide will remain anonymous. A report of findings will be produced but this will not release any individual responses or the names of participants in the survey. Please contact us, if you would like to discuss the research project.

Yours faithfully,

Dr Andrew Barnes
Senior Agricultural Economist

Miss Eleonore Guillem
Postgraduate Researcher

Name:
Address:

Please do not pass my contact details on to the research contractor. I do not want to take part in the research.

«Parish» / «Holding»

1	Gender	Male ❑ Female ❑
2	What is your age?	18-25 ❑ 26-35 ❑ 36-50 ❑ 51-65 ❑ over 65 ❑
3	Are you?	Tenant ❑ Owner ❑ Partly tenant/Partly owner ❑
4	What is your education level?	Primary ❑ Secondary ❑ College ❑ University ❑ None ❑
5	For how many years have you been in farming?	Up to 10 ❑ 11-20 ❑ more than 20 ❑
6	Are you the main decision maker on the farm?	Yes ❑ No ❑
7	Do you keep production records?	Yes ❑ No ❑
8	Do you have any on-farm non-agricultural activities? (e.g. Bed& breakfast, Horses…)	Yes ❑ No ❑
9	Do you have any of the following activities on the farm?	Birdwatching ❑ Game shooting ❑ Fishing ❑ Other ❑
10	Do you intend to pass on the farm on to a family member?	Yes ❑ No ❑
11	How much of your total income comes from farming alone?	Less than 50% from farm ❑ 50-75% from Farm ❑ All from farm ❑
12	Have you received any conservation advice in the last year?	Yes ❑ No ❑
13	Are you a member of a conservation organisation (RSPB, SNH, FWAG)	Yes ❑ No ❑

14	**In terms of making decisions about the farm, how often do you:**	**Never**	**Occasionally**	**Regularly**	**Very frequently**
a	- consult with your family	❑	❑	❑	❑
b	- consult the internet	❑	❑	❑	❑
c	- consult media (TV, radio, newspapers)	❑	❑	❑	❑
d	- attend open days or	❑	❑	❑	❑

	demonstration activities				
e	- meet with other land managers	❑	❑	❑	❑
f	- talk to a conservation advisor	❑	❑	❑	❑
g	- talk to a farm advisor (SAC, FWAG etc.)	❑	❑	❑	❑
15	**How often do you check for updates on:**				
a	- new farming methods	❑	❑	❑	❑
b	- new crop varieties	❑	❑	❑	❑
c	- policies	❑	❑	❑	❑
d	- market	❑	❑	❑	❑
e	- environmental issues	❑	❑	❑	❑

Below are some comments gathered from a discussion with farmers. There is no right or wrong answer only your view on the question, *please tick one box per question that most closely reflects your view.*

Attitudes towards Farming					
		Strongly Disagree	**Disagree**	**Agree**	**Strongly Agree**
16	As a farmer I feel close to nature	❑	❑	❑	❑
17	One of the best things in farming is the lifestyle	❑	❑	❑	❑
18	On a farm this size you have to be orientated towards production to survive	❑	❑	❑	❑
19	Maintaining a 'tidy' landscape is important for me and the community	❑	❑	❑	❑
20	Preserving the traditional appearance of the area is important for me and the community	❑	❑	❑	❑
Attitudes and Knowledge about Environmental issues					
21	Farmers have a responsibility	❑	❑	❑	❑

	towards maintaining the quality of the environment				
22	What my neighbour does on his farm influences the quality of the environment on my farm	❑	❑	❑	❑
23	In the past 5 years, I have noticed a decrease in bird numbers in the region	❑	❑	❑	❑
24	Switching from crops to grass will negatively affect farmland bird populations	❑	❑	❑	❑
25	Having only one or two different crop types on the farm will not adversely affect wildlife	❑	❑	❑	❑
Attitudes and Knowledge about Biodiversity					
26	I enjoy seeing different types of birds on my farm	❑	❑	❑	❑
27	Birds can help lower the number of insects on the farm	❑	❑	❑	❑
28	My farm provides good habitats for birds	❑	❑	❑	❑
Attitudes towards Environmental Policies					
29	There is insufficient information about agri-environmental measures	❑	❑	❑	❑
30	Agri-environmental schemes will deliver long-term benefits to wildlife	❑	❑	❑	❑
31	I would uptake more agri-environmental schemes if I could	❑	❑	❑	❑
32	Agri-environmental measures will increase the risk of disease and pest problems	❑	❑	❑	❑
33	Agri-environmental schemes should be more flexible for my farm	❑	❑	❑	❑

Business Objectives					
34	**Please rate the following priorities for your business**	**Not important**	**Slightly important**	**Quite Important**	**Very important**
a	To obtain the greatest amount of profit from my resources	❑	❑	❑	❑
b	To make enough money to keep my family and those I employ comfortable	❑	❑	❑	❑
c	To ensure there is a business/holding for my successors when I retire	❑	❑	❑	❑
d	To ensure I have time to spend with my family/friends	❑	❑	❑	❑
e	To maintain respect within the local community	❑	❑	❑	❑
f	To remain independent and increase my self-reliance	❑	❑	❑	❑
g	To improve wildlife and biodiversity	❑	❑	❑	❑
h	To provide a service to society by producing food	❑	❑	❑	❑

What informs Land Use Change?					
35	**Have any of the following had an influence on changing your land management decisions?**	**No Effect**	**Slight Effect**	**Some Effect**	**Big Effect**
a	Changes in input prices	❑	❑	❑	❑
b	Advice from consultants	❑	❑	❑	❑
c	Observing other farmers in the region	❑	❑	❑	❑
d	Changes in output prices	❑	❑	❑	❑
e	Introduction of newer technology	❑	❑	❑	❑

f	Changes in policy and regulations	❑	❑	❑	❑
g	Consequences of Climate change	❑	❑	❑	❑

36	**Have you adopted any agri-environmental schemes in the past? (e.g. RSS, LMCM, CPS)**	**Yes** ❑		**No** ❑	
TO INTERVIEWER: If Yes: '*what made you adopt the agri-environmental scheme?', if* **NO***: 'what would make you adopt an agri-environmental scheme?'*					
		No Influence	**Slight influence**	**Some Influence**	**Big Influence**
a	To increase cash flow for the business	❑	❑	❑	❑
b	To use surplus labour on the farm	❑	❑	❑	❑
c	It easily fitted in with the way I manage the farm already	❑	❑	❑	❑
d	To improve the wildlife habitats on my farm	❑	❑	❑	❑
e	To provide a better environment for me and my family to live in	❑	❑	❑	❑
f	To improve soil quality and reduce erosion	❑	❑	❑	❑
If No: *What would make you adopt an agri-environmental scheme?*					
g	More flexibility in agri-environmental schemes	❑	❑	❑	❑
h	Wanting more wildlife on the farm	❑	❑	❑	❑

37	**In your opinion which of the following will have an effect on your future land use?**				
		Negative Effect	**Unlikely Effect**	**Some Positive Effect**	**Strong Positive Effect**
a	Climate change	❑	❑	❑	❑
b	Increased payment for environmental management	❑	❑	❑	❑
c	Increased viability of energy crops	❑	❑	❑	❑
d	Increased viability of forestry	❑	❑	❑	❑

	production				
e	Increased viability of non-farming activities	❑	❑	❑	❑
f	Increasing viability of organic farming	❑	❑	❑	❑
g	Reintroduction of set-aside	❑	❑	❑	❑

38	**In order to satisfy my objectives I aim to:**	**No**	**Unlikely**	**Yes, maybe**	**Yes, strong possibility**
a	Adopt the best yielding varieties	❑	❑	❑	❑
b	Keep my cropping system as it is	❑	❑	❑	❑
c	Rent/Purchase more land	❑	❑	❑	❑
d	Put more land into agri-environmental measures	❑	❑	❑	❑
e	Diversify into newer crops, including energy crops	❑	❑	❑	❑
f	Diversify into different activities, such as forestry or tourism	❑	❑	❑	❑
g	Plant more spring crops	❑	❑	❑	❑
h	Leave winter cover	❑	❑	❑	❑
i	Invest in more efficient machinery	❑	❑	❑	❑
j	Convert to organic production	❑	❑	❑	❑
k	Maintain a low input system	❑	❑	❑	❑
l	Adopt voluntary environmental measures	❑	❑	❑	❑
m	Increase field size to maximize efficiency	❑	❑	❑	❑
39	**Would you grow a highly profitable crop even if:**				
a	Past prices were unstable	❑	❑	❑	❑
b	Past yields could be low, due to the weather	❑	❑	❑	❑
c	It is a new crop which you've never grown before	❑	❑	❑	❑
d	It has never been grown in the	❑	❑	❑	❑

	region before				

40. **We hope to follow up the questionnaire with some workshops to explore your thoughts further. Would you be willing to be contacted over this?** ❑

Appendix C

Additional Outputs – Chapter 3

- ***Information sources and themes***

One factor of considerable importance in decision making is the network of information exchange. This acts as a crossing point between action and perception (Toma and Mathijs, 2007). On the one hand it can explain the perceptions held by a certain type of farmers and on the other hand it opens ways through which the information signal can pass. Improving the information directed at specific farmers is key to behavioural change (Brodt et al., 2006; Sutherland et al., 2011). Table C.1 displays the frequency with which farmers seek information and the themes they look for. Across all types, farmers consult most frequently with family members. Profit-oriented farmers tend to consult with open sources of information such as the media and the internet. They tend not to consult with farming-background sources (other farmers, focus groups, farm advisors). The themes they research are mainly related to profit and production techniques. In contrast, the information network of multifunctionalists is varied, but particularly concentrated on farm-related sources. The themes into which they research are also more diverse. They frequently seek updates on policies and environmental issues. Traditionalist farmers concentrate on family to make decisions but discuss on a variety of themes at least occasionally with other farmers.

To be more effective, the information on sustainable farming practices and AES must be directed to suit varied perceptions, objectives and needs. Different approaches, from individualistic to more collective ones, should be considered to deliver information successfully. With the administration of Rural Development Contracts (RDC), the government is distilling funding locally where "they will provide the greatest public benefit" (Scottish Government[29]). For that reason, information should be prepared in a way that it is accepted by farmers, that is "culturally sustainable" and that could be spread within the community by a "trusted" source of information (Morris and Potter, 1995; Harrison et al., 1998; Skerratt, 1998; Morris, 2006; Burton et al., 2008). The message given should emphasize all aspects of decision making so that it is appealing to a broad range of land holders. For instance, financial consequences, landscape appearance, social cost, and environmental outcomes have to be addressed.

Table C.1 – Mean responses for Information sources and themes (1: Never, 2: Occasionally, 3: Regularly, 4: Very frequently)

	Profit-oriented	Multifunct-ionalist	Traditionalist	Hobbyist
Have you received conservation advice in the last year (%)	19	10	27	0
How often do you consult with…				
Family	2.38	2.60	3.27	2.40
Other farmers	1.81	2.20	1.93	1.00
Open days/ focus group	1.94	2.20	1.60	1.20
Farm advisor	1.81	2.30	1.67	1.00
Media	2.44	1.80	1.67	1.60
Internet	2.06	2.00	1.87	2.20
How often do you check for updates on…				
Market	2.62	2.60	2.60	1.20
New farming methods	2.25	2.10	2.33	1.00
New crop varieties	2.25	2.10	2.13	1.00
Policies	2.19	3.00	2.07	1.60
Environmental issues	2.19	2.80	2.53	1.60

[29] http://www.scotland.gov.uk/Topics/farmingrural/SRDP/KeyMessage

- ***Motivations to AES participation***

Farmers were asked about what did, or would, motivate them to participate in AES and these are described in figure C.1. 37% of profit-oriented farmers had adopted AES in the past. The reason for this low take up is associated with low interest in ecological issues and their reluctance to change practices. Indeed, the main motivations for applying voluntary measures, although none of them had particularly strong influences, were financial and managerial. Other studies found similar styles of participation (e.g. passive adopter: Morris and Potter, 1995; opportunist: Fish et al. 2003). The AES participants within this group are seeking maximum economic benefit from a scheme and most commonly, these farmers might register their hedges or winter cover practices as options that they already applied.

Of all the types, the multifunctionalists had the highest uptake level of AES in the past (60%). The main motivations for this were the improvement in biodiversity, in the family environment, and in soil condition. Moreover, this group is made up of the highest number of farmers who practice game shooting on their land. Measures such as grass margins and beetle banks are particularly appealing to them. The same practices also prevent soil erosion. This type is similar to the Fish et al.'s "engaged farmers" and Morris and Potter's "active adopters". A positive relationship between innovative farmers and participation in AES has been demonstrated elsewhere (Willock et al. 1999a; Schmitzberger et al. 2005). Although for most multifunctionalists, ease of fit within the farming system and income are important reasons for applying AES.

In the past, 40% of traditionalist farmers in the sample adopted AES. Although they are unwilling to take up more AES in the future, their main motivation would be to create a better environment for the family, to improve soil condition and for the benefit of wildlife. These findings are in opposition with the low level of UNA factor that characterises this cluster. A similar participation style, "catalysing style", was found by Fish et al. (2003) for which income loss might be limited by applying measures mainly on less productive areas.

Only 20% of hobbyists have participated in AES in the past, mainly for improving wildlife habitats and the family environment. They are engaged, but are strongly limited by the size of their farms. They also noted that ease of fit had some influence in adopting a scheme. Shucksmith & Hermann (2002) suggest that hobbyists invest little in their farms and do not feel involved in the process of agri-environment schemes, although they would be encouraged if AES was accessible to very small farms.

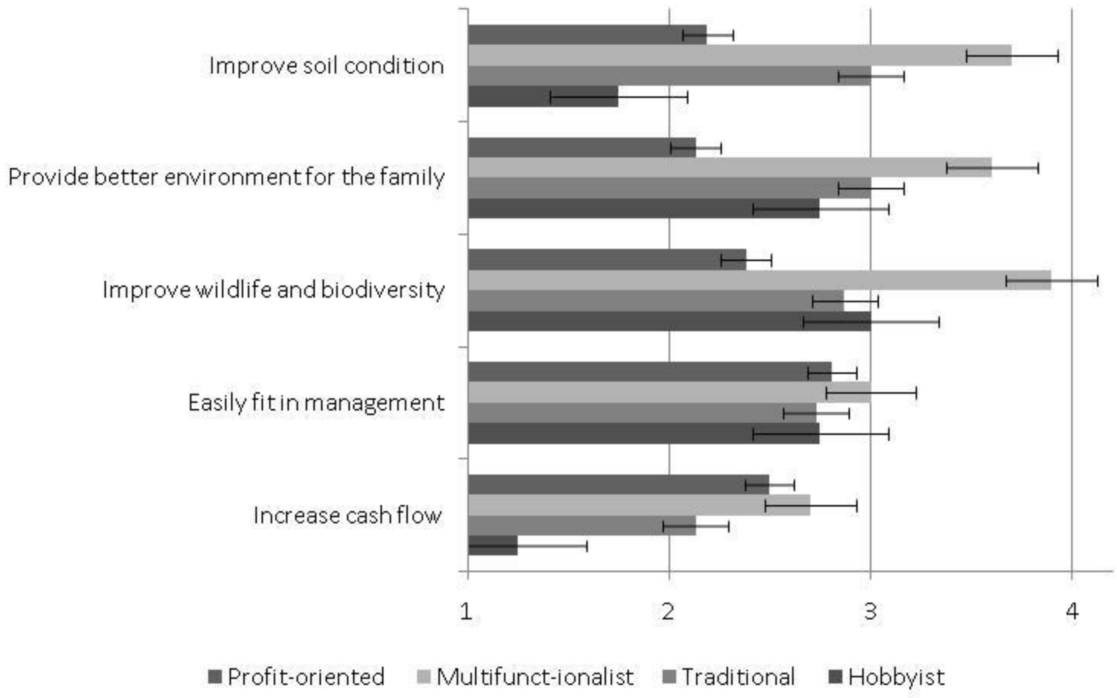

Figure C.1 - Mean responses for Motivations to AES participation for each cluster with standard deviation in brackets (1: No influence, 2: Slight influence, 3: Some influence, 4: Big influence).

Appendix D

Choice-Based Conjoint Experiment

The following questionnaire is the second phase of the social survey aiming at:

- collecting data on preferences for land use decision,
- investigating the trade-offs of land use decision attributes,
- estimating attributes importances and attribute levels preferences of each farmer attitudinal type.

Farmers who agreed to participate in the follow-up survey were sent the questionnaire by mail post in the winter 2009. The presented questionnaire is one version out of the five different versions sent to the farmers. The questionnaire is preceded by an explanatory introduction that stipulates the confidentiality of the data collected and a guide to complete the tasks. At the end of the questionnaire, further explanations are provided.

We are investigating farmer decisions in the Lunan, particularly in relation to land use and agri-environmental measures. This is part of a **RERAD** funded project led by ***SAC*** (*Scottish Agricultural College)* researchers on land use and agri-environmental measures. Through this survey, we hope to gain more knowledge on land use and the decisions that are most relevant to Scottish arable farmers. There are no '*right*' or '*wrong*' answers; we are simply interested in your opinion and your experiences. The survey will take approximately 20 minutes to complete.

All your answers are anonymous and will be kept strictly confidential, being used solely for the present study. Your opinions and experiences are very valuable to us. If you are interested to know more about the project, please contact Eleonore.Guillem@sac.ac.uk

Please could you complete the survey and return in the enclosed, postage-paid envelope provided to:
Scottish Agricultural College F.A.O Eleonore Guillem, King's Buildings, West Main Road, Edinburgh EH9 3JG

FARM DECISION TASKS

The following exercise will help researchers to understand in more detail farmers' preferences in making decision. Below you will find 12 decision tasks (**In this appendix, only a sample of 7 tasks is shown**); in each task presented there are five different options for farming activities. We would like to know what decisions you would make for an available piece of land of around 10% of your farm (e.g. 10 ha for a farm of 100 ha) on the basis of the options presented in each task. Two types of land are presented: **type A** is of marginal type to agricultural use, (e.g. ex-set aside, grade 4, 5 or lower) and **type B** is a good quality land, (e.g. grade 2 to 3.2).

You will be asked to make a decision for each of these tasks, regardless of your current and actual activities. The options in each task are described according to six attributes, including farming activities (e.g. cropping, livestock, environmental management), required effort involved, social feedback, impact on the environment, level of possible risk and changes to income. An appendix is available at the end of the questionnaire for further guidance on attributes and options. It may be confusing that farming activity and other attributes are randomly distributed in each task but option labels (1, 2, 3, 4 and 5) are purposefully **not** associated with a particular attribute.

Please complete as many tasks as possible and, if you wish, you can supply additional information at the end of the questionnaire. Remember, all the information you provide will be strictly confidential and anonymous. Thank you very much for your help!

TASK 1

Attributes	Option 1	Option 2	Option 3	Option 4	Option 5
Farm activity	Crop	Livestock	Non-Food*	Manage environment*	Crop with protected Field Margin
Required effort	No change	More work	Less work	No change	Less work
Social Feedback*	Negative	Negative	None	Positive	Positive
Environment*	Maintain	Degrade	Degrade	Enhance	Enhance
Level of risk	High	Low	High	Low	Medium
Change in income	No change	+ 10%	+ 10%	- 10%	- 10%

** Appendix at the end for further information*

Please, select the option that you would apply for each land type A and B.
If the piece of land is of **type A** (marginal), I would choose Option…
If the piece of land is of **type B** (good quality), I would choose Option…

Given the uncertainties in global climate and economic conditions as well as in European agricultural policies, would you realistically choose the above options? Yes □ No □

TASK 2

Attributes	Option 1	Option 2	Option 3	Option 4	Option 5
Farm activity	Manage environment*	Crop	Non-Food*	Livestock	Crop with protected field margin
Required effort	Less work	Less work	No change	More work	No change
Social Feedback*	Positive	Positive	Negative	None	None

Environment	Degrade	Maintain	Enhance	Maintain	Enhance
Level of risk	High	Medium	Medium	Low	High
Change in income	- 10%	+ 10%	No change	+ 10%	- 10%

** Appendix at the end for further information*

Please, select the option that you would apply for each land type A and B.
If the piece of land is of **type A** (marginal), I would choose Option…
If the piece of land is of **type B** (good quality), I would choose Option…

Given the uncertainties in global climate and economic conditions as well as in European agricultural policies, would you realistically choose the above options? Yes □ No □

TASK 3

Attributes	Option 1	Option 2	Option 3	Option 4	Option 5
Farm activity	Non-Food*	Livestock	Crop	Crop with protected field margin	Manage environment*
Required effort	No change	Less work	More work	More work	No change
Social Feedback*	Positive	Positive	Negative	Negative	None
Environment	Maintain	Enhance	Degrade	Degrade	Maintain
Level of risk	High	High	Low	Low	Medium
Change in income	+ 10%	+ 10%	No change	No change	- 10%

** Appendix at the end for further information*

Please, select the option that you would apply for each land type A and B.
If the piece of land is of **type A** (marginal), I would choose Option…
If the piece of land is of **type B** (good quality), I would choose Option…

Given the uncertainties in global climate and economic conditions as well as in European agricultural policies, would you realistically choose the above options? Yes □ No □

TASK 4

Attributes	Option 1	Option 2	Option 3	Option 4	Option 5
Farm activity	Livestock	Crop with protected field margin	Non-Food*	Manage environment*	Crop
Required effort	More work	No change	Less work	Less work	More work
Social Feedback*	Negative	Positive	None	None	Positive
Environment	Degrade	Maintain	Degrade	Enhance	Enhance
Level of risk	Medium	High	Medium	Low	Low
Change in income	- 10%	+ 10%	No change	No change	- 10%

** Appendix at the end for further information*

Please, select the option that you would apply for each land type A and B.
If the piece of land is of **type A** (marginal), I would choose Option…
If the piece of land is of **type B** (good quality), I would choose Option…

Given the uncertainties in global climate and economic conditions as well as in European agricultural policies, would you realistically choose the above options? Yes □ No □

TASK 5

Attributes	Option 1	Option 2	Option 3	Option 4	Option 5
Farm activity	Manage environment*	Livestock	Crop	Non-Food*	Crop with protected field margin
Required effort	More work	No change	Less work	Less work	More work

Social Feedback*	None	Positive	Negative	Negative	None
Environment	Degrade	Enhance	Maintain	Maintain	Enhance
Level of risk	High	Medium	High	Low	Medium
Change in income	+ 10%	No change	No change	- 10%	+ 10%

** Appendix at the end for further information*

Please, select the option that you would apply for each land type A and B.
If the piece of land is of **type A** (marginal), I would choose Option…
If the piece of land is of **type B** (good quality), I would choose Option…

Given the uncertainties in global climate and economic conditions as well as in European agricultural policies, would you realistically choose the above options? Yes □ No □

TASK 6

Attributes	Option 1	Option 2	Option 3	Option 4	Option 5
Farm activity	Non-Food*	Crop	Manage environment*	Livestock	Crop with protected field margin
Required effort	More work	Less work	More work	No change	No change
Social Feedback*	Positive	None	Positive	Negative	Negative
Environment	Enhance	Enhance	Maintain	Degrade	Degrade
Level of risk	High	High	Medium	Low	Low
Change in income	- 10%	+ 10%	No change	- 10%	+ 10%

** Appendix at the end for further information*

Please, select the option that you would apply for each land type A and B.
If the piece of land is of **type A** (marginal), I would choose Option…
If the piece of land is of **type B** (good quality), I would choose Option…

Given the uncertainties in global climate and economic conditions as well as in European agricultural policies, would you realistically choose the above options? Yes □ No □

TASK 7

Attributes	Option 1	Option 2	Option 3	Option 4	Option 5
Farm activity	Livestock	Non-Food*	Crop with protected field margin	Manage environment*	Crop
Required effort	Less work	No change	Less work	More work	No change
Social Feedback*	None	Negative	Negative	Positive	None
Environment	Maintain	Degrade	Maintain	Enhance	Degrade
Level of risk	Low	Medium	Medium	High	Low
Change in income	- 10%	+ 10%	- 10%	+ 10%	No change

** Appendix at the end for further information*

Please, select the option that you would apply for each land type A and B.
If the piece of land is of **type A** (marginal), I would choose Option…
If the piece of land is of **type B** (good quality), I would choose Option…

Given the uncertainties in global climate and economic conditions as well as in European agricultural policies, would you realistically choose the above options? Yes □ No □

Which of the attribute(s) did you consider in making the task choices?

Farm activity □ **Required effort □** **Social Feedback □**

Environment □ **Level of risk □** **Change in income □**

Can you think of any other attributes not taken into account in the tasks that have particular importance in making this kind of decision? …………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

ADDITIONAL INFORMATION

At what age do you intend to retire?

Before 55 □ Between 56 and 65 □ Between 66 and 75□

After 75 □ Don't know □ Already retired □

What will you do with your land once retired?

Sell □ Rent □ Pass it onto a family successor □

Keep unmanaged □ Other □ Please specify…………………………………………

Do you agree with this statement? "*Agri-environmental cooperation schemes amongst farmers can benefit wildlife****"***

Strongly disagree □ Disagree □ Unsure □ Agree □ Strongly agree □

Would you join an agri-environmental cooperation scheme?

Not at all □ Unlikely □ I Don't know □ Maybe □ Likely □

If you would join, indicate the reason(s) for joining:

Improve ecological benefit □

Reduce costs □

Additional income □

Share of information □

Improve local landscape □

Allow greater flexibility □

*** Guidance for the Farm Decision Task ***

In the ***farm activity***, the production of "*non-food" refers to timber, bio-energy crops, eco-tourism*. "Manage environment" refers to activities that aims to protect species habitat, improve biodiversity, or improve quality of soil and water and that are applied to the entire piece of land (e.g. management of species-rich grassland option of the Rural Stewardship Scheme). "Crop with protected field margin" refers to agri-environmental measure (e.g. grass margins and beetlebank or water margin options of the Rural Stewardship Scheme).

Required effort describes the level of work you will have to invest in the farming activity chosen. The work can be related either to the activities on the farm if it is a labour-intensive activity or to paperwork due to bureaucracy in subsidy application.

Social feedback describes how the general public and other local farmers react to the activity (i.e. appreciate or complain) because of its effects on the environment, food supply and quality, or their property.

Environment describes how the activity will affect the level of soil erosion, the amount of chemicals (fertilisers and pesticides) present in the surrounding water bodies, and the quality of local habitat for birds.

Level of risk describes the level of risks due, for example, to unstable market (e.g. decrease in output price), to climate variability (e.g. decline in yield), or to your lack of experience on this activity.

Change in income describes the additional income earned or lost for the option chosen compared with your standard revenue.

Appendix E

CBC: Good Quality versus Marginal Land

The following tables show the hierarchical bayes analysis results of the choice-based conjoint experiments for each farmer type (Table E.2 to E.5) and for a population average (Table E.1). The top part of each table contains the *preferences* for each level of each attribute. The bottom part displays the *importance* of each attribute, which is a percentage over all attributes considered. These values, i.e. preferences and importances, are given for two set of CBC experiments: one is related to land of good quality (G), and one for the marginal land (M) (see Appendix D).

In Chapters 4 and 5, only the attributes (and their levels) “Social feedback”, “Environmental impact” and “Income” were taken into account in the multi-attribute utility function. However, the tables show the effects of other attributes such as “required effort” and “farm activities, and of land quality on farmer decisions. This suggests that, in further development of the model, more attributes could be added in the utility function, and a spatially-explicit decision process could be implemented. The latter would require data on land quality, which is available for the Lunan catchment (Land Capability Map, see Appendix I, Figure I.5).

Table E.1 – Average preference structure for the whole sample. G: Good quality land, M: Marginal land, N: number of farmers who answered the CBC experiment

Attributes	**Levels**	**G (N=12)**	**M (N=9)**
Farm activities	Crop	29.21	-55.89
	Livestock	-62.84	9.31
	Non-Food	-24.48	18.19
	Manage Environment	-10.61	47.70
	Crop+Field Margin	68.72	-19.31
Required effort	No change	22.61	3.18
	More work	-23.93	-12.42
	Less work	1.32	9.23
Social feedback	None	-9.47	-8.97
	Positive	35.23	13.59
	Negative	-25.75	-4.62
Environmental impact	Maintain	4.99	4.32
	Degrade	-43.48	-50.10
	Enhance	38.49	45.78
Risk	Average	4.89	4.99
	Low	5.21	1.49
	High	-10.10	-6.48
Income	No change	-6.40	-10.46
	+ 10%	74.22	71.11
	- 10%	-67.82	-60.65
Attributes: Average Importances (%)			
	Farm activity	29.95	36.31
	Required effort	11.35	7.33
	Social feedback	11.42	8.42
	Environment	15.52	17.37
	Level of risk	6.90	6.42
	Income	24.86	24.15

Table E.2 – Preference structure of the Profit-oriented. G: Good quality land, M: Marginal land, N: number of farmers who answered the CBC experiment

Attributes	Levels	G (N=4)	M (N=2)
Farm activities	Crop	80.35	-104.29
	Livestock	-46.54	4.26
	Non-Food	-11.37	37.90
	Manage Environment	-85.44	67.12
	Crop+Field Margin	63.00	-4.98
Required effort	No change	20.57	-16.08
	More work	-4.66	-0.67
	Less work	-15.91	16.76
Social feedback	None	-9.75	17.34
	Positive	24.50	-12.51
	Negative	-14.75	-4.83
Environmental impact	Maintain	26.20	-20.00
	Degrade	-40.98	-55.59
	Enhance	14.78	75.59
Risk	Average	9.59	12.03
	Low	4.92	-14.09
	High	-14.52	2.06
Income	No change	-20.92	-28.52
	+ 10%	70.26	72.87
	- 10%	-49.34	-44.36
Attributes: Average Importances (%)			
	Farm activity	33.80	30.95
	Required effort	12.00	5.54
	Social feedback	9.07	9.77
	Environment	14.35	21.86
	Level of risk	7.29	4.50
	Income	23.50	27.38

Table E.3 - Preference structure of the Multifunctionalist. G: Good quality land, M: Marginal land, N: number of farmers who answered the CBC experiment

Attributes	**Levels**	**G (N=3)**	**M (N=3)**
Farm activities	Crop	-0.60	-35.91
	Livestock	-59.20	17.01
	Non-Food	-11.93	18.15
	Manage Environment	13.34	52.78
	Crop+Field Margin	58.39	-52.02
Required effort	No change	26.21	1.42
	More work	-40.65	-7.89
	Less work	14.43	6.47
Social feedback	None	-19.12	-28.33
	Positive	40.40	30.65
	Negative	-21.28	-2.32
Environmental impact	Maintain	-13.80	25.74
	Degrade	-43.12	-41.99
	Enhance	56.91	16.24
Risk	Average	0.71	0.22
	Low	9.44	15.64
	High	-10.15	-15.86
Income	No change	-10.14	-5.22
	+ 10%	98.74	91.46
	- 10%	-88.60	-86.24
Attributes: Average Importances (%)			
	Farm activity	24.16	34.39
	Required effort	11.30	6.29
	Social feedback	11.13	9.83
	Environment	17.36	12.19
	Level of risk	4.82	7.69
	Income	31.22	29.62

Table E.4 - Preference structure of the Traditionalist. G: Good quality land, M: Marginal land, N: number of farmers who answered the CBC experiment

Attributes	Levels	G (N=3)	M (N=3)
Farm activities	Crop	20.48	-59.35
	Livestock	-105.64	30.75
	Non-Food	-68.79	8.83
	Manage Environment	47.13	33.51
	Crop+Field Margin	106.82	-13.74
Required effort	No change	16.60	-1.50
	More work	-14.71	-6.56
	Less work	-1.88	8.06
Social feedback	None	-6.67	-0.58
	Positive	26.44	-2.34
	Negative	-19.78	2.92
Environmental impact	Maintain	7.84	6.62
	Degrade	-40.30	-49.22
	Enhance	32.46	42.60
Risk	Average	12.48	10.55
	Low	0.10	0.30
	High	-12.57	-10.85
Income	No change	4.28	-3.04
	+ 10%	58.64	55.87
	- 10%	-62.92	-52.83
Attributes: Average Importances (%)			
	Farm activity	41.87	48.13
	Required effort	7.60	4.88
	Social feedback	8.50	3.57
	Environment	12.13	17.01
	Level of risk	9.64	6.96
	Income	20.26	19.46

Table E.5 - Preference structure of the Hobbyist . G: Good quality land, M: Marginal land, N: number of farmers who answered the CBC experiment

Attributes	Levels	G (N=2)	M (N=1)
Farm activities	Crop	-15.27	-8.65
	Livestock	-36.71	-67.98
	Non-Food	-3.07	6.98
	Manage Environment	16.53	36.21
	Crop+Field Margin	38.53	33.44
Required effort	No change	30.32	61.08
	More work	-51.23	-67.09
	Less work	20.91	6.01
Social feedback	None	1.34	-28.70
	Positive	62.08	62.41
	Negative	-63.42	-33.72
Environmental impact	Maintain	-13.52	-18.19
	Degrade	-53.82	-66.08
	Enhance	67.34	84.27
Risk	Average	-9.63	-11.42
	Low	7.11	-6.23
	High	2.52	17.66
Income	No change	12.23	-12.35
	+ 10%	68.73	52.22
	- 10%	-80.96	-39.86
Attributes: Average Importances (%)			
	Farm activity	13.05	17.36
	Required effort	15.74	21.36
	Social feedback	20.92	16.02
	Environment	20.19	25.06
	Level of risk	5.15	4.85
	Income	24.95	15.35

Appendix F

Additional Outputs – Chapter 4

In Chapter 4, average partial utilities for economic, social and environmental attributes of farm strategies were given for each farmer type under the three ALARM scenarios (Figure 4.9). The partial utilities resulting from simulated decisions show the level of satisfaction of farmers in terms of finance, environmental impacts and social feedbacks. This appendix displays partial utilities over time, which offer a detailed understanding of farmer decisions in terms of planning. Indeed, “by enabling agents to choose amongst regimes, which may also differ in their temporal extent, the agent can plan for the future as well as make choices in the present”. For instance, on Figure F.1, we can see that the multifunctionalist farmers have a long term planning strategy. They sacrifice the financial aspect today in order to obtain a better income in the future. Oppositely, the profit-oriented farmers choose regimes, which maximise their income at present and every year. This observation is however less evident in the GRAS scenario, where farmers are forced to adapt to price signals (Figure F.2).

The social and environmental partial utilities are relatively stable over time under all scenarios (Figures F.4 to F.6). This may indicate a willingness from all farmers to maximise these attributes in all contexts.

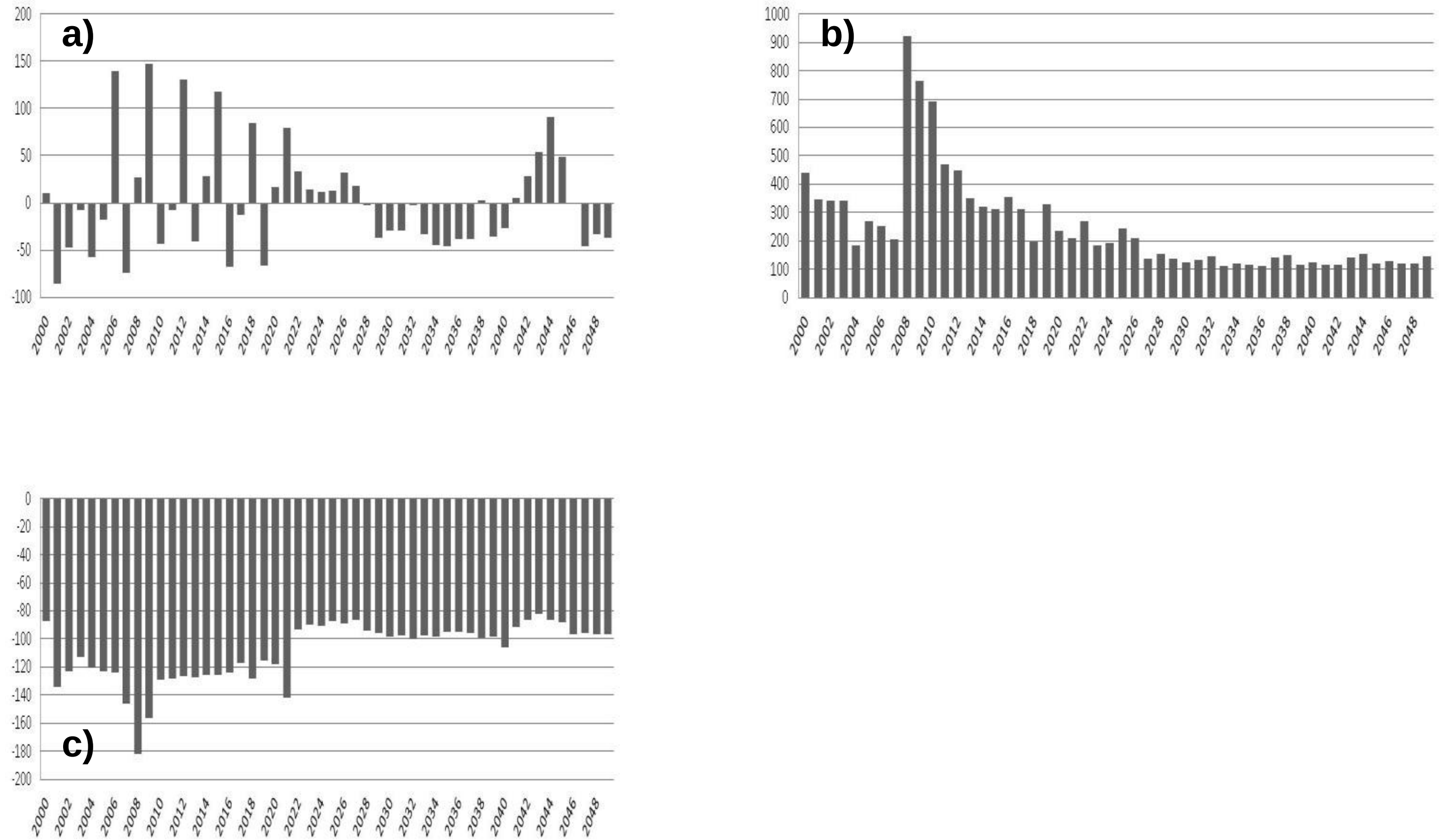

Figure F.1 - Economic partial utility in BAMBU for a) Multifunctionalists, b) Profit-oriented, and c) Traditionalists

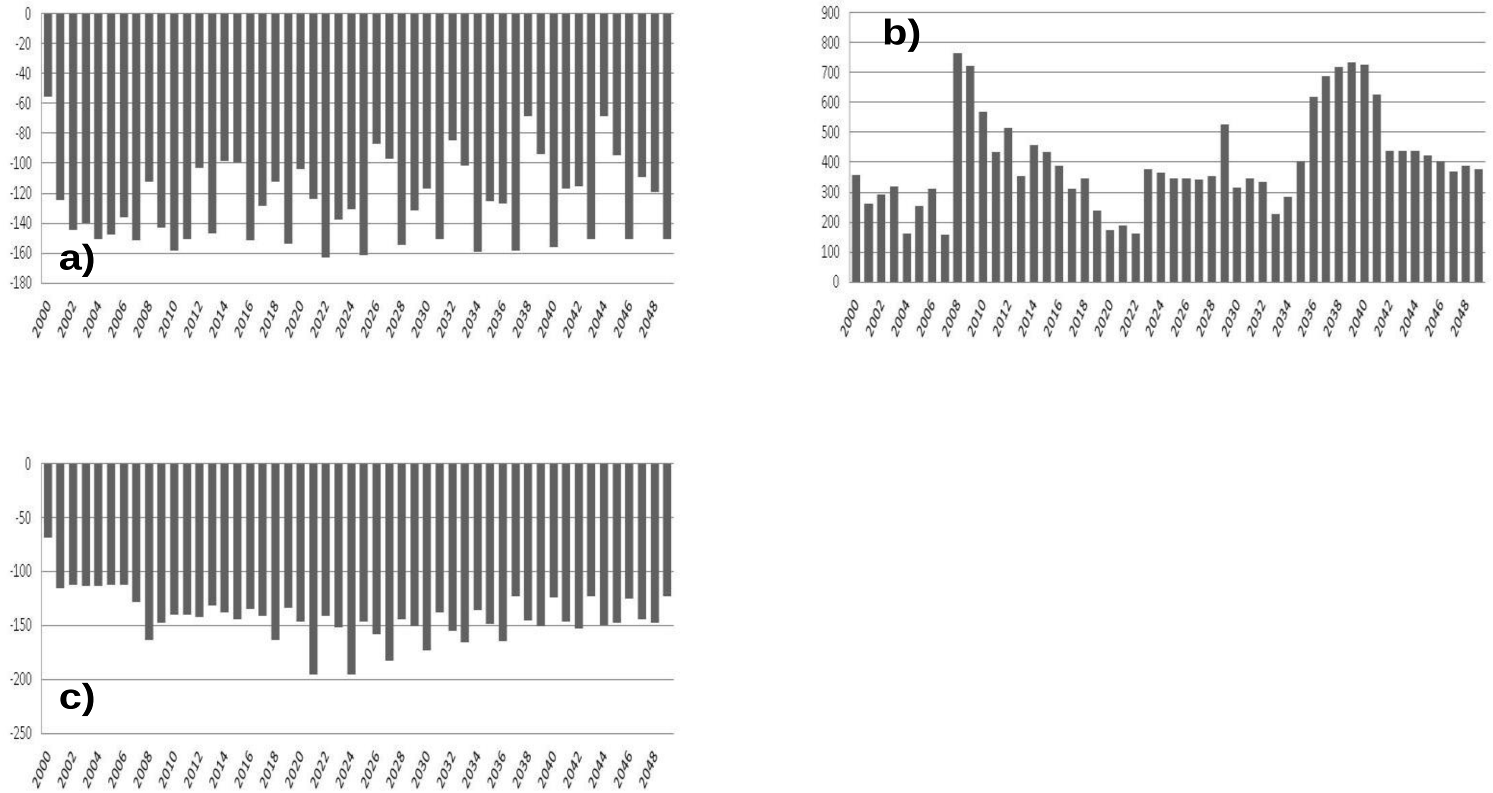

Figure F.2 - Economic partial utility in GRAS for a) Multifunctionalists, b) Profit-oriented, and c) Traditionalists

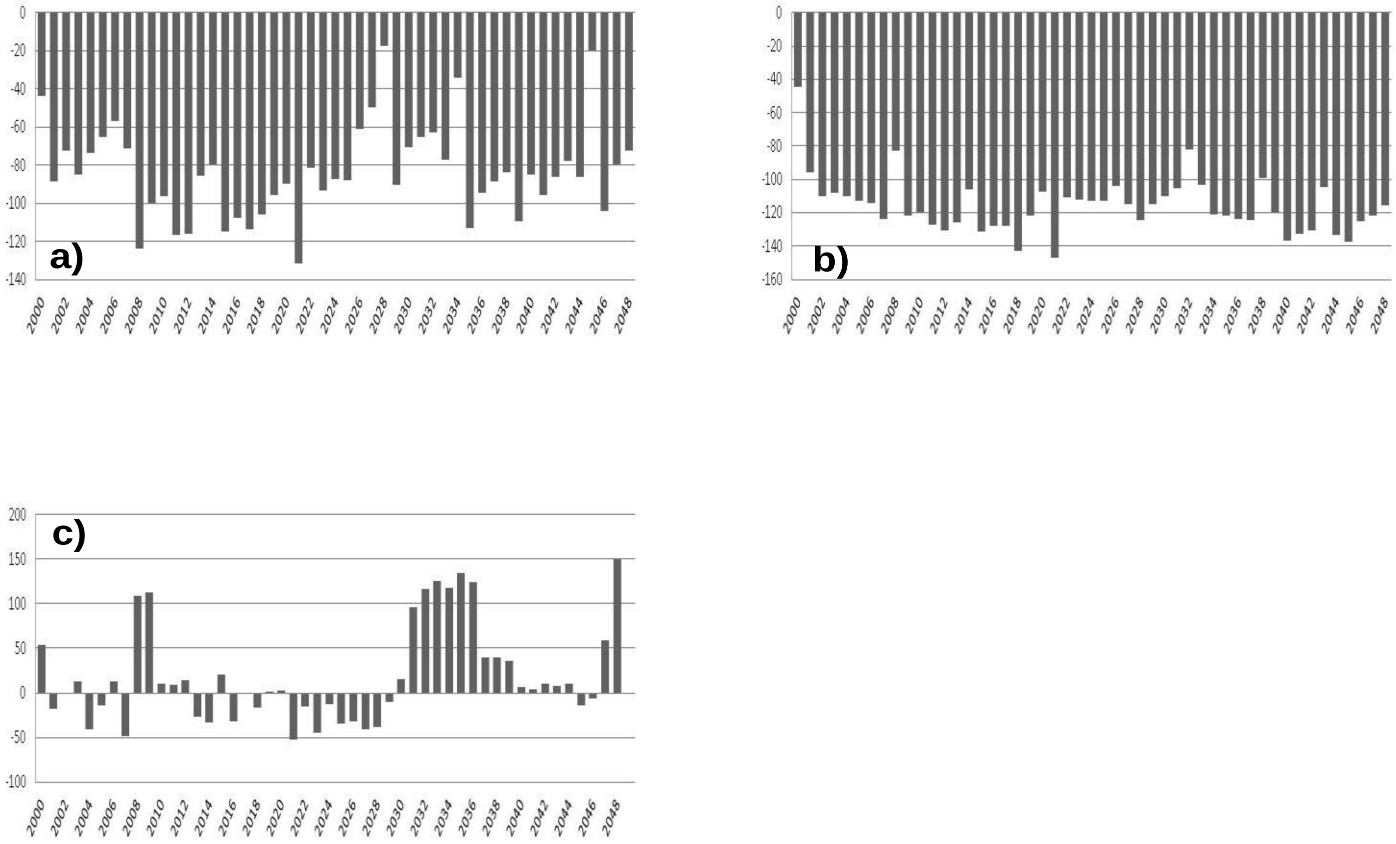

Figure F.3 - Economic partial utility in SEDG for a) Multifunctionalists, b) Profit-oriented, and c) Traditionalists

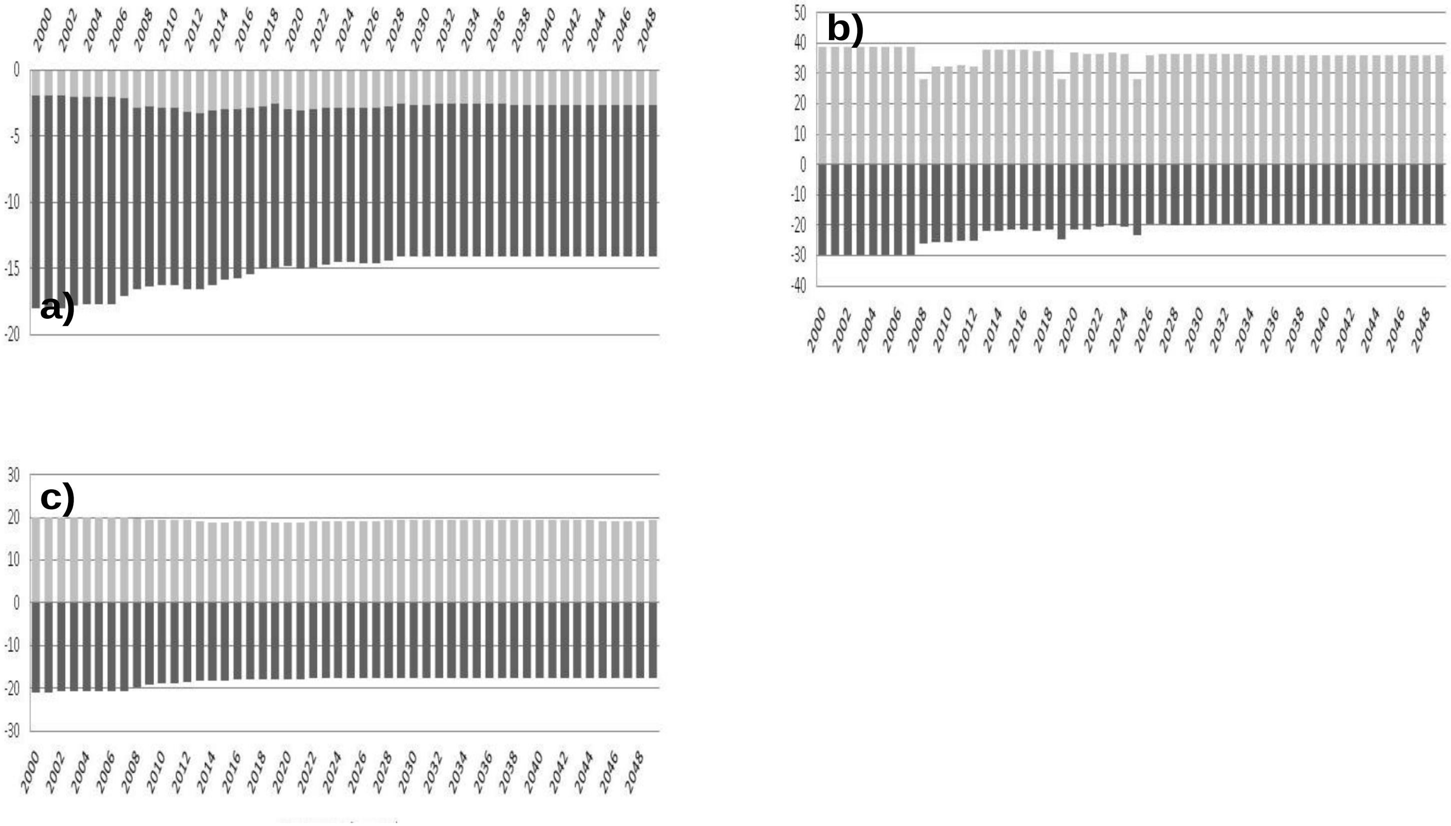

Figure F.4 - Environmental (light grey) and Social (dark grey) partial utilities in BAMBU for a) Multifunctionalists, b) Profit-oriented, and c) Traditionalists

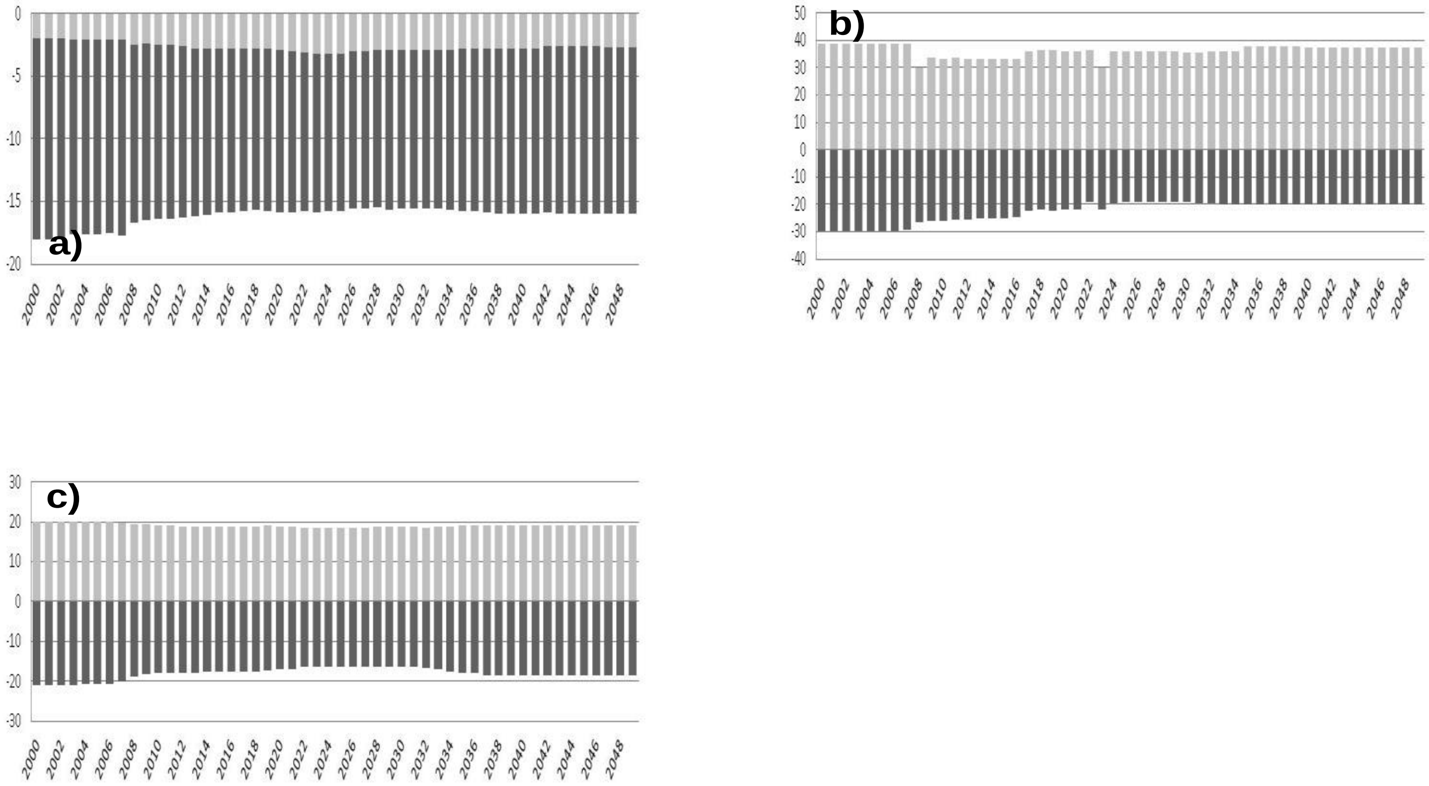

Figure F.5 - Environmental (light grey) and Social (dark grey) partial utilities in GRAS for a) Multifunctionalists, b) Profit-oriented, and c) Traditionalists

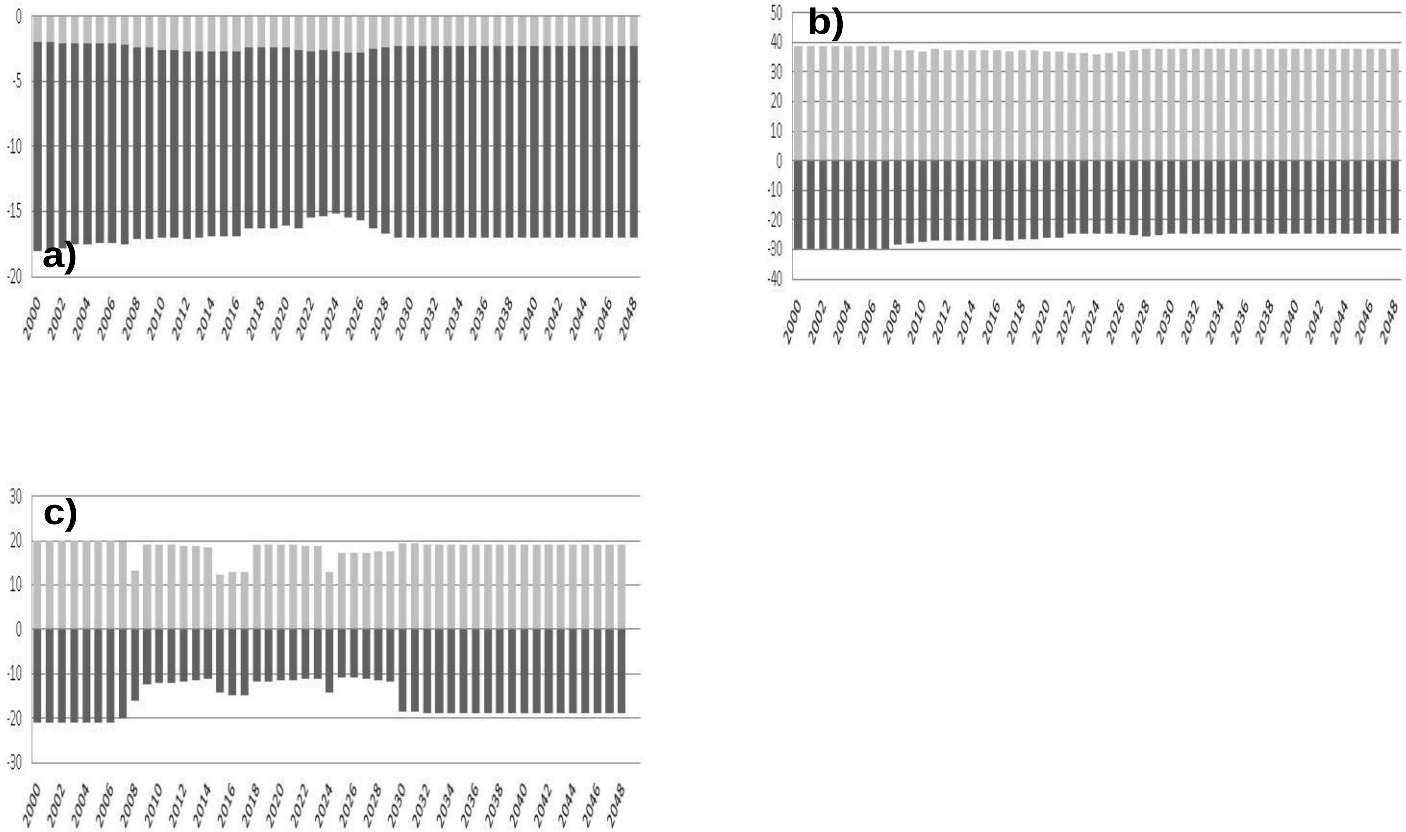

Figure F.6 - Environmental (light grey) and Social (dark grey) partial utilities in SEDG for a) Multifunctionalists, b) Profit-oriented, and c) Traditional

Appendix G

Skylark Field Survey

Adapted from Guillem, E.E. 2009. *Agricultural land use and seasonal variation in territory density for skylarks Alauda arvensis in the Lunan Catchment, Scotland.* Manuscript

1. Introduction

The skylark is a common farmland bird species that is embedded within ecosystem services since it has cultural importance, especially in the UK. Indeed, these birds are mainly found in arable areas where they act as a traditional inhabitant for the farmers who manage these lands. However, its UK population has been strongly declining since the 70’s due to the intensification of the agriculture (Siriwardena et al., 1998; Chamberlain and Siriwardena, 2000; Chamberlain et al., 2000; Donald et al., 2001a). The species, for which the breeding population is red listed in the UK (Eaton et al., 2009), is one of the top biodiversity indicators to assess the environmental sustainability of agricultural areas (DEFRA).
A large literature is available on the species breeding ecology and the causes of decline in agricultural areas. It has been found that vegetation structure is an important factor of territory suitability since an optimum height and density act as a compromise between protection against predator and foraging (Wilson et al., 1997; Poulsen et al., 1998; Chamberlain et al., 1999; Donald et al., 2001b; Pierce-Higgins and Grant, 2006). Crop management and types of activities are thus essential element of nest suitability for skylarks. Skylarks are nesting within crops from the beginning of April to early August (Donald, 2004) and can breed up to 4 times a year depending on the suitability of a nesting site (Delius, 1965; Eraud and Boutin, 2002; Donald et al., 2001c; Toepfer and Stubbe, 2001). The number of territories is associated with the crop type as reported in expert studies (O’Connor and Shrubb, 1986; Wakeham-Dawson et al., 1998; Poulsen et al., 1998; Chamberlain et al., 1999; Donald et al., 2001b; Toepfer and Stubbe, 2001) giving a constraint of density-dependence. Territory density is a common measure for the assessment of the suitability of crop type as a breeding habitat.

A large number of studies have already been carried out that show these measures, although they occurred mainly in England and do not take account of spatial and temporal variation within a same breeding season. Most studies have underlined the possible intra-seasonal variations in territory densities but only few have explicitly investigated (Chamberlain et al., 1999; Toepfer and Stubbe, 2001; Eraud and Boutin, 2002; Thomsen, 2002).

The collection of observational data is needed to improve our knowledge of skylark’s breeding success, especially in Scotland for which data is scarce. This research investigates the seasonal variations in skylark nest territory through fieldwork and the closely related farming management in Scotland.

2. Methods

2.1 Fieldwork

For the purpose of this work, we selected a 132 km2 catchment in East Scotland that is mainly arable (spring and winter sown cereals, potatoes, peas and oilseed rape). To estimate precisely territory densities, a minimum of 40 observations need to be recorded (Bibby et al., 1992), and a minimum of 5 observations per crop type and visit is required[30]. Hence, 49 fields that belong to three different farms that are representative of the area have been sampled by one observer (Figure G.1). From April to July 2009, a visit occurs every 2 weeks between 7am to 12am. In total, eight visits of two days permit the analysis of temporal and spatial variation within the landscape. The validity of the collected data depends on the protocol requirements which are: i) same crop to be surveyed at each visit, and ii) alternate order of visitation to minimize effects related to time of day (Bibby et al., 1992; Gilbert et al., 1998). Wind and heavy rain is avoided due to diminishing skylark activity (Wilson et al., 1997).

The survey follows the spot mapping method (Gregory et al., 2004; Gilbert et al., 1998; Bibby et al., 1992) which consists of noting each individual skylark encountered on a 1:12000 raster map. The observer walks through tramlines, in each field, and collects data on the number of skylarks encountered, vegetation height and density, type of linear features and crop types. Tramlines have been chosen to represent transect in order to avoid disturbing nesting birds and damaging crops. Encounters could involve male, female, juvenile and floater and, to avoid overestimation and to obtain an absolute estimate of breeding population, only breeding males were recorded. Breeding males are easily recognized thanks to their typical singing and hovering. When a bird is seen at the edge between two fields, each is treated as containing 0.5 territories.

[30] Jeremy Wilson, RSPB, pers. Comm.

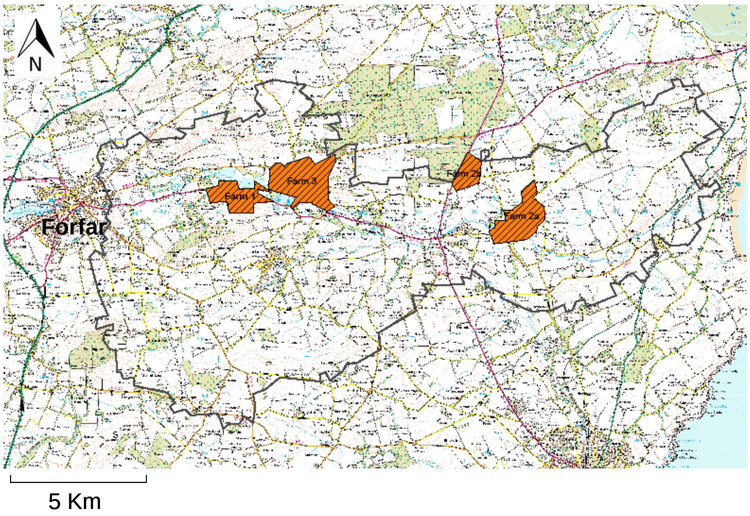

Figure G.1 – Lunan catchment boundaries and location of the farms surveyed

The mean vegetation height and density characterise crop type structure. 15 points per field are randomly selected to measure height. In addition, a photo of each field is used to determine the density of plantation. Field area is estimated by using the GIS spatially-explicit IACS data[31].

2.2 Analysis of results

A mean and standard deviation was calculated for territory per hectares T for each crop type i and each period of visit $t_1 \ldots t_n$, with $n = 8$ (Equation 1).

$$T_{i,n} = \sum_{p=1}^{p} (N_p / A_p) + \Delta_{i,n} \tag{1}$$

,with N_p the number of male skylark observed in parcel p, A_p the area of the parcel and Δ_i the standard deviation. It is assumed that a visit of a crop leads to the count of all the individuals[1]. Therefore, the mean observations for each visit and for

[31] Integrated Administration and Control System

each crop are calculated at 95% confidence limits. Precision and accuracy of the observations are assessed by comparing the results of other studies (e.g. Poulsen et al., 1998; Browne et al., 2000; Donald et al., 2001b; Beulke et al., 2007). In addition, the breeding population within the whole catchment *P* is estimated through Equation 2.

$$P = \sum\left[\left(\overline{T}_i \cdot 2\right) \cdot A_i\right] \qquad (2)$$

This is reproduced over the period 2001 to 2008 for which historical land uses were obtained from the IACS data. The population trend over this period is then compared with the one estimated by the Breeding Bird Survey (Raven et al., 2002, 2003, 2004, 2005, 2007; Raven and Noble, 2006; Risely et al., 2008, 2009, 2010).

For each parcel, a mean vegetation height is derived from the 15 random measurements. A quadratic regression analysis is then applied to territory density against vegetation height.

3. Results

3.1 Characteristics of the sample

Table G.1 shows the area surveyed during the eight visits. In total more than 360 hectares were surveyed at each visit. The reduced number of fields surveyed for peas, potatoes and silage imply that the accuracy of the territory density calculations is poorer than for cereals.

Figure G.2 presents an example of the composite map on which skylark observations are recorded. The symbols used are BTO standard activity recording conventions (Gilbert et al., 1998).

Table G.1 – Area and crop types sampled in 2009

	Number of parcel and Area Surveyed (Ha)				Mean Size of Fields (StDev)		
Crop Type	*Farm 1*	*Farm 2*	*Farm 3*	***Total***	*Farm 1*	*Farm 2*	*Farm 3*
Peas	3	2	0	**5**	6.185	1.035	-
	10.30	2.07	0	**12.37**	± 0.12	±0.40	
Potatoes	1	2	3	**6**	16.92	6.715	6.1
	16.92	13.43	18.28	**48.63**		± 1.2	± 0.86
Silage	5	0	0	**5**	4.9	-	-
	24.47	0	0	**24.47**	± 2.22		
Spring Barley	7	6	0	**13**	7.54	11.62	-
	52.82	69.72	0	**122.54**	± 2.65	± 4.3	
Winter Barley	3	2	0	**5**	6.48	2.1	-
	15.23	4.20	0	**19.43**	± 0.44	± 1.02	
Winter Oat	0	0	3	**3**	-	-	4.42
	0	0	13.25	**13.25**			± 2.3
Winter Wheat	2	4	1	**7**	10.955	12.215	7.16
	21.91	48.86	7.16	**77.93**	± 0.47	± 0.86	
Winter Oilseed	0	5	0	**5**	-	8.624	-
Rape	0	43.12	0	**43.12**		± 2.97	
TOTAL	**21**	**21**	**7**	**49**	**-**	**-**	**-**
	147.92	**175.13**	**38.69**	**361.74**			

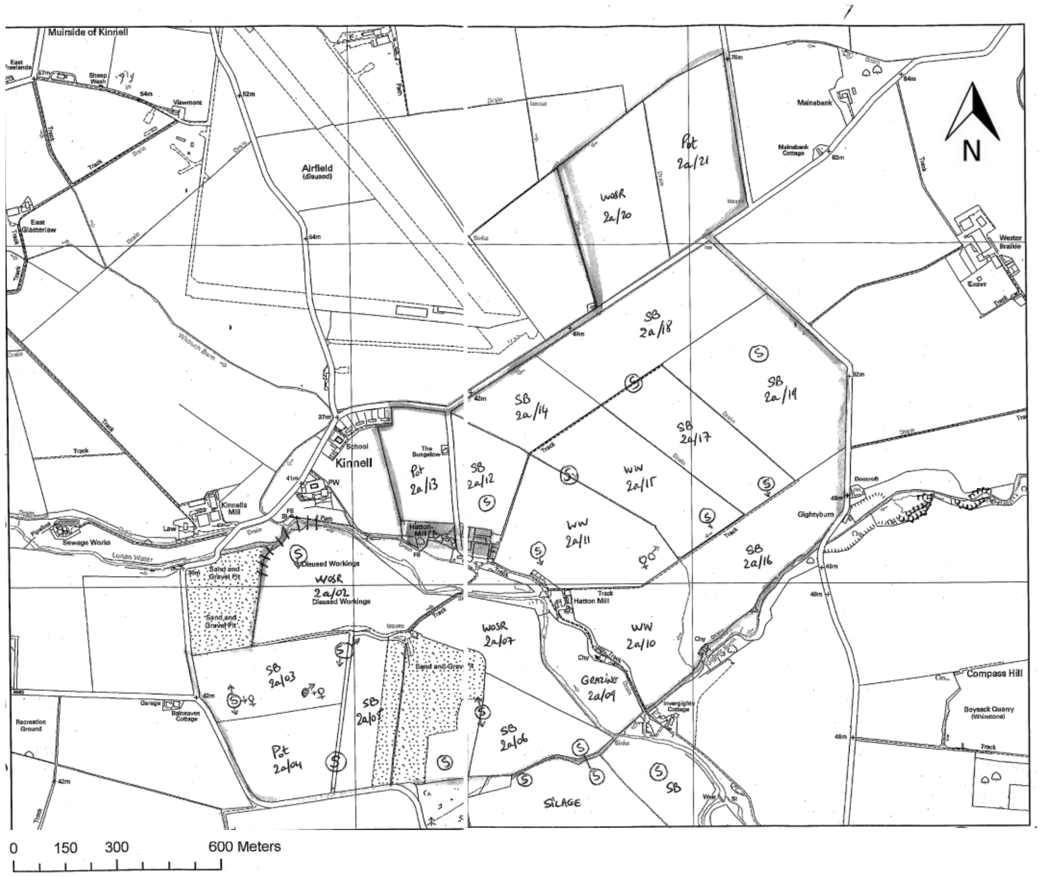

Figure G.2 – skylark observations on the 17 of April 2009 on farm 2a. Refer to Gilbert et al. (1998) for symbol definition

3.2 Mean territory densities and Breeding population trend

The overall average of skylark territory density in the Lunan catchment is estimated at 0.104 territories per hectare. This value is in accordance with other studies (0.12 territory per hectare: O'Connor and Shrubb, 1986; Poulsen et al., 1998) The average territory densities per crop type over the whole period are higher for legumes and cereals, in particular spring barley and winter wheat (Figure G.3). The vegetation structure of leguminous crops is suitable for nest establishment over the whole period of cultivation. Spring cereal was known for supporting higher density of skylark territories compared with winter cereal (e.g. Browne et al., 2000; Toepfer and Stubbe, 2001). However the survey carried out in the Lunan demonstrated a higher density in winter wheat. In general the densities found in this study are relatively similar with the ones from other more extensive surveys (Table G.2).

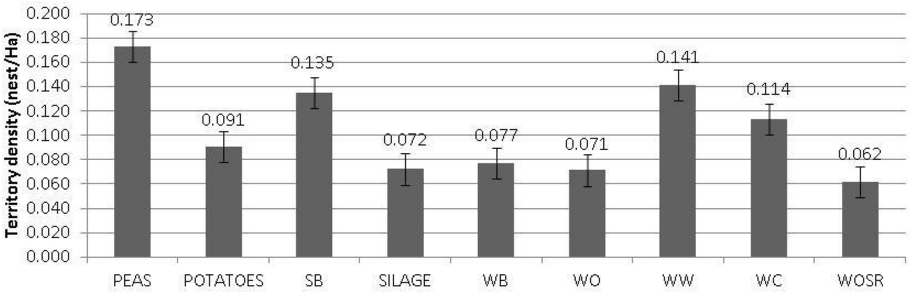

Figure G.3 - Mean territory density (nest per hectare) for each crop type.

Table G.2 – Literature review on territory densities

Crop type	**Territory densities (terr. /ha)**
Peas	0.125[4]
Potatoes	0.005[4] ;0.108[2]
Spring cereals	0.3[3] ;0.122[2] ;0.55[5]
Winter cereals	0.22[1] ;0.107[2] ;0.141[5] ;0.3 [6]
Silage	0.01[3] ;0.084[2]
OSR	0.15[5] ;0.021[4] ;0.090[2]

[1]: Poulsen et al., 1998 ; [2]: Browne et al., 2000 ; [3]: Donald et al., 2001b ; [4]: Beulke et al. 2007 ; [5]: Toepfer and Stubbe, 2001 ; [6]: Chamberlain et al., 1999

I have used an average territory density from the Breeding Bird Survey (BBS) for the Tayside region to assess the population trends in the Lunan catchment. The population estimate computed with the field survey data (Equation 2) is more optimistic than the one calculated with BBS data (Figure G.4). The Tayside region is composed of intensive arable farmland and also little hills and forests. The BBS estimation could therefore be biased due to the heterogeneity in habitats compared with our survey which focuses on farmland only. However, this survey is far too short to allow this inference with confidence, although, the trend estimated using this survey shows analogous patterns as the trend estimated with BBS data. A decrease in

2006 could be due to the effect of decoupling, followed by a stable increase up until 2009. During the period 2008-2010, more cereal crops were planted to respond to market signals, providing a better habitat for the breeding skylark.

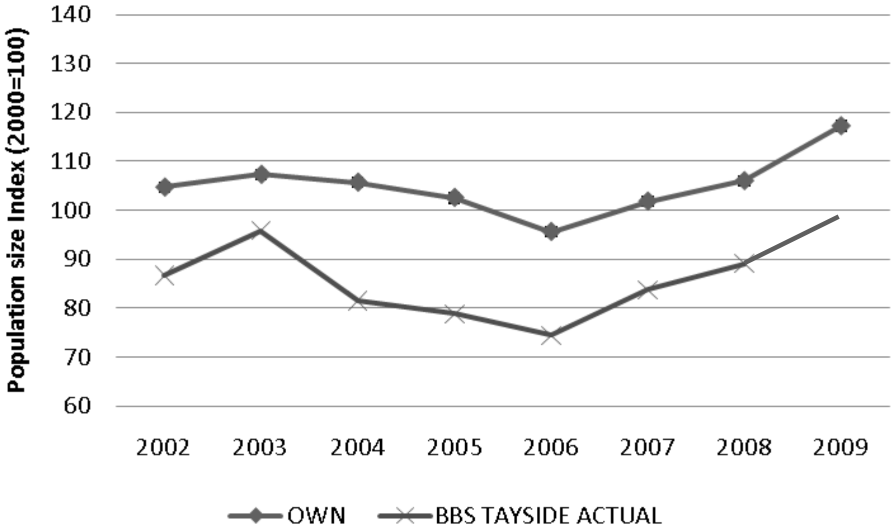

Figure G.4 - Comparison of skylark population trend using the field survey data (OWN) and the Breeding Bird Surveys (BBS) for the Tayside region. The OWN trend is estimated by multiplying territory density specific to crop type with the area of each crop type specific for a given year

3.3 Effect of vegetation height

The quadratic regression shows the best fit to the collected data (Figure G.5). Although it only explains about 7% of the variation in territory density, an optimum height is observed at about 60 cm. Many studies have been carried out that show relatively similar optimum range, although it is usually smaller: 25 to 90 cm (Poulsen et al., 1998), 15 to 60 cm (Toepfer and Stubbe, 2001), around 55 cm (Donald et al., 2001b).

The poor R-squared can be related to the fact that the vegetation height is not crop type specific. Poulsen et al. (1998) have demonstrated that the vegetation height optimum ranges are different for both crop type and timing. This was due to the small number of data point to consider.

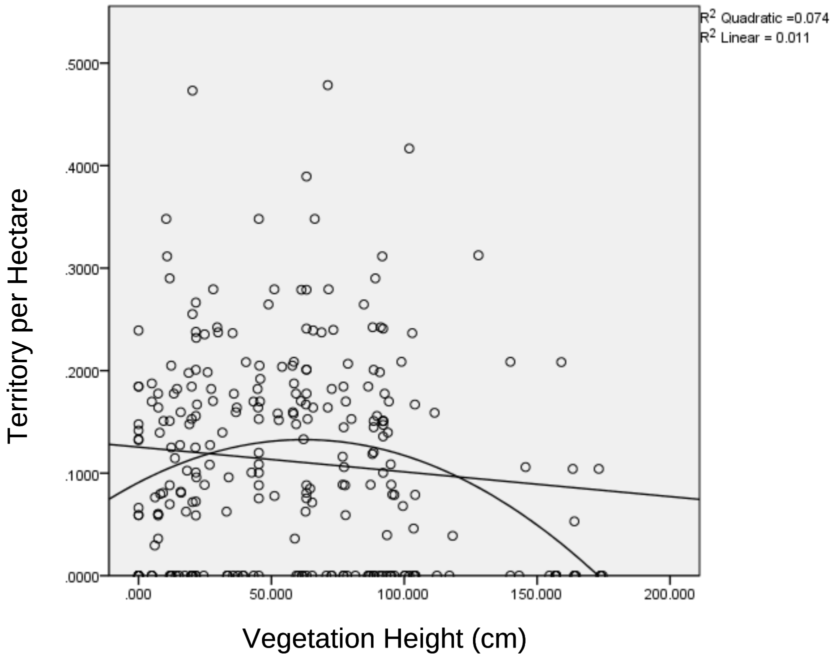

Figure G.5 – Scatterplot representing the relationship between territory density and vegetation height. A linear and quadratric regression lines are added to best fit the data

3.4 Seasonal variations in territory density

Across a breeding season, from April to July, there are variations in the density of territories (Figure G.6). However, for spring cereal crops the average density is relatively uniform for the whole period of reproduction and starts to diminish from the beginning of July while this density is already low in mid June in winter-sown cereals.

There is a pick of density in both peas and potatoes crops around mid-June. At this time these crops have vegetation height of about 50 to 70 cm, which is the optimum height found in this study.

The presence of skylark nesting in oilseed rape crops (winter-sown only) occurs at the beginning of the breeding season when the crop is not too tall and dense. From mid-May, no skylarks were spotted on these crops.

The density of territory found on silage fields corresponds with the time of grass cutting in mid-May.

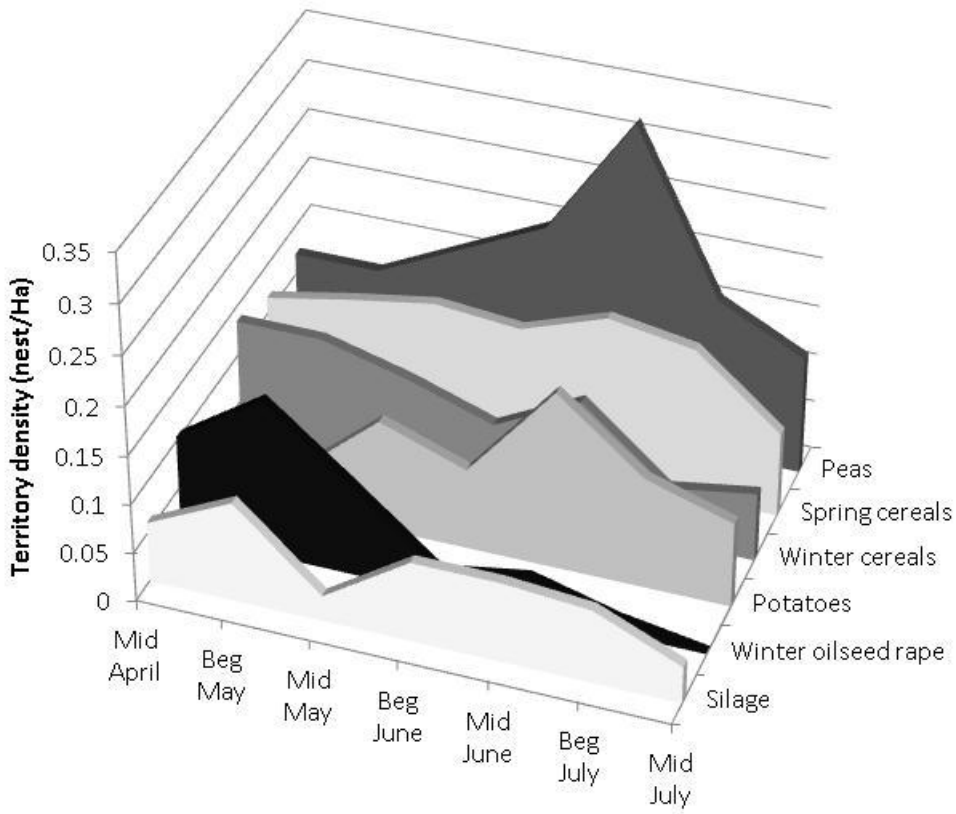

Figure G.6 – Seasonal variation on skylark territory density with regards to crop type

4. Discussion and Management recommendations

This study focused on the detection of skylarks breeding in a small intensive arable Scottish catchment for the estimation of territory densities with regards to crop type and seasonal variations.

On average males skylark establish their nest with the highest density on cereal and peas fields. These findings suggest that these crop types are best suitable to skylark breeding. Winter wheat crops were found to support, on average, a similar density of skylark territories than spring-sown cereals. This is in contradiction with numerous studies carried out on the species. However, the other winter-sown cereal crops (oat and barley) had lower densities and this was particularly observable from the second half of the breeding season (beginning of June). Other authors claimed that winter-sown cereal crops are not suitable for breeding skylark during this period (Wilson et al., 1997; Donald et al., 2001b; Thomsen, 2002). However, in Scotland, the vegetation growth of both winter- and spring-sown crops is limited by the climate, probably leading to less dense vegetation, which grows slower, than is found in southern England and other continental countries (Whittingham et al., 2003).

On average, legumes crops had the highest territory density but the study showed that this is due to a pick occurring when the vegetation was about 60 cm. In addition, these picks could correspond with the decrease in territory density observed in oilseed rape and winter cereals, suggesting that the skylarks would establish nests in adjacent fields when the latter have become unsuitable. This was also shown in other works, e.g. Schlapfer, 1988; Jenny, 1990; Chaney, 1997, and suggest that legumes crops are not the optimal type of crop but are sub-optimal. Indeed, these crops were the least dense of all the fields surveyed, i.e. around 25% coverage which is sun-optimal habitat according to Toepfer and Stubbe (2001).

The seasonal variation in territory densities seem to be explained by vegetation height and thus farming management, e.g. silage cutting (Jenny, 1990; Poulsen, 1996; Toepfer and Stubbe, 2001). The optimum vegetation height for nest establishment was probably biased by the variety of crop types surveyed and due to less dense vegetation. Also the seasonal variation makes the average territory densities not perfectly adequate to predict territory occupation since it is only at the beginning of the breeding season that all crop types surveyed supported skylark territories, e.g. in winter oilseed rape (Donald et al., 2001b; Thomsen, 2002; Donald, 2004).

The intra-seasonal variations in the selection of territories are mainly defined by two picks (when territory number is at the highest) that occur in mid-May and mid-June in cereal crops and potatoes. The occurrence of territory establishment picks at given time implies recommendations for when farming operations should be carried out (e.g. spraying, cutting). These operations should be avoided during period of high territory establishment activities.

The abundance of invertebrates has been linked to the vegetation structure and type (Wakeham-Dawson et al., 1998; Atkinson et al., 2004), which can explain the preference of skylarks for certain crops, for instance spring barley (Poulsen et al., 1998), but this abundance could also be related with climate, topography and the access to predators. The type of linear features around a parcel and the proximity to forest patches is particularly relevant for the selection of territory to avoid predators

(Schlapfer, 1988; Suhonen et al., 1994; Chamberlain and Gregory, 1999; Praus and Weidinger, 2010), although a study has shown that it did not affect nest survival (Donald et al., 2002). However, the small number of data collected on linear features did not allow for robust statistical analysis, and therefore the estimated territory densities could be over or under-estimated. The size of field was also not considered, even if it has been shown to have an effect on the suitability for territories (Wilson et al., 1997; Donald et al., 2001b).

Appendix H

Maps – Chapter 5

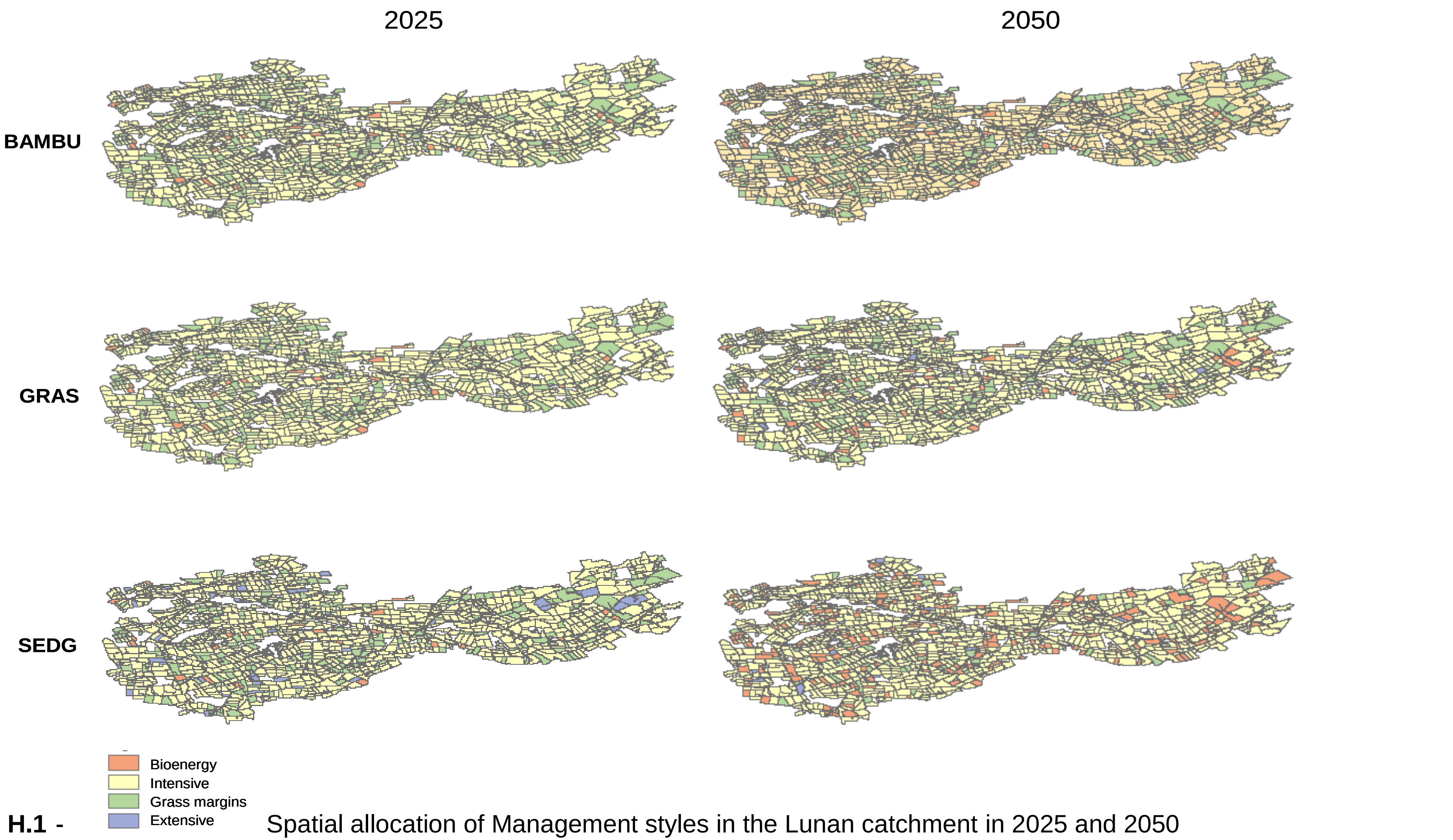

Figure H.1 - Spatial allocation of Management styles in the Lunan catchment in 2025 and 2050

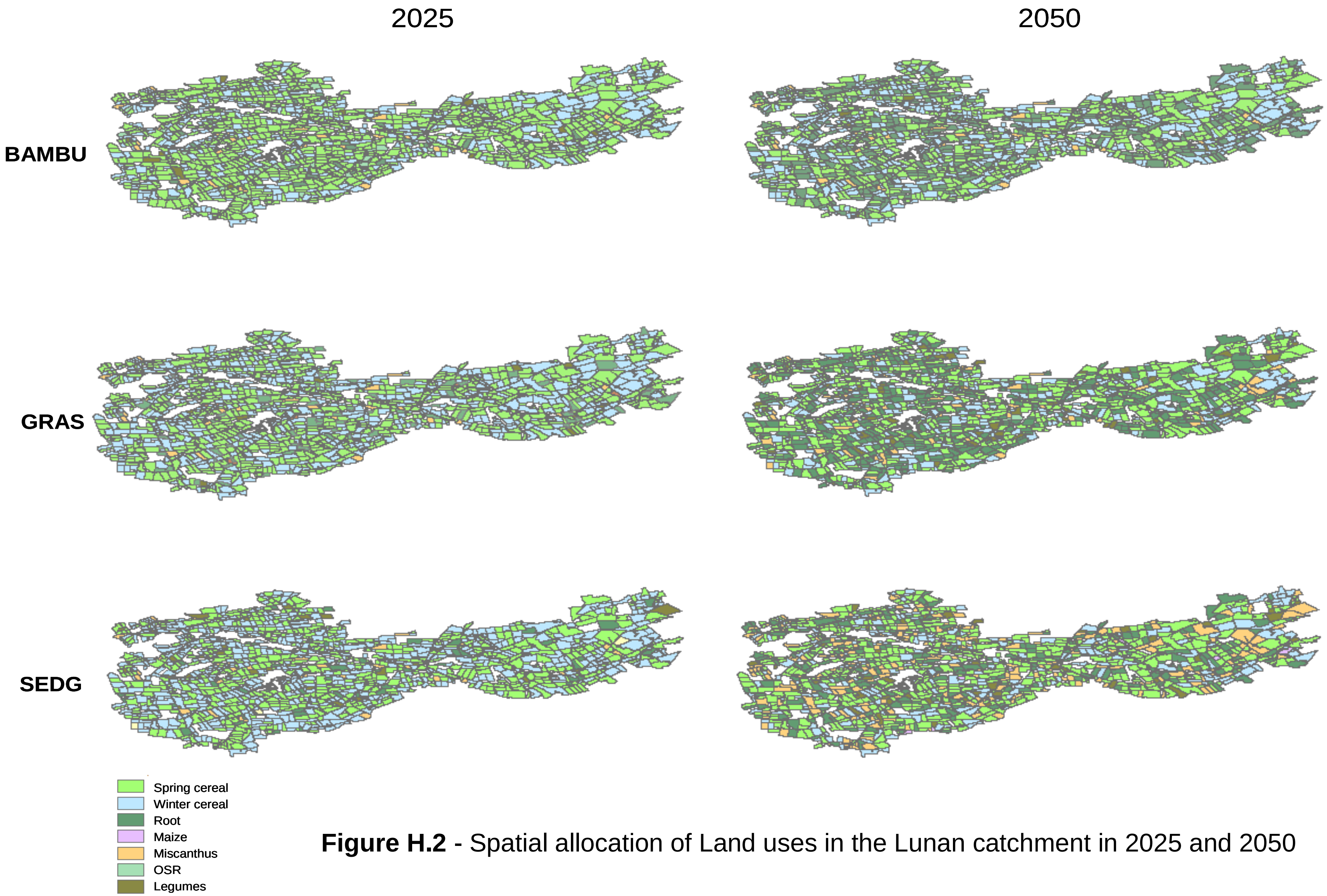

Figure H.2 - Spatial allocation of Land uses in the Lunan catchment in 2025 and 2050

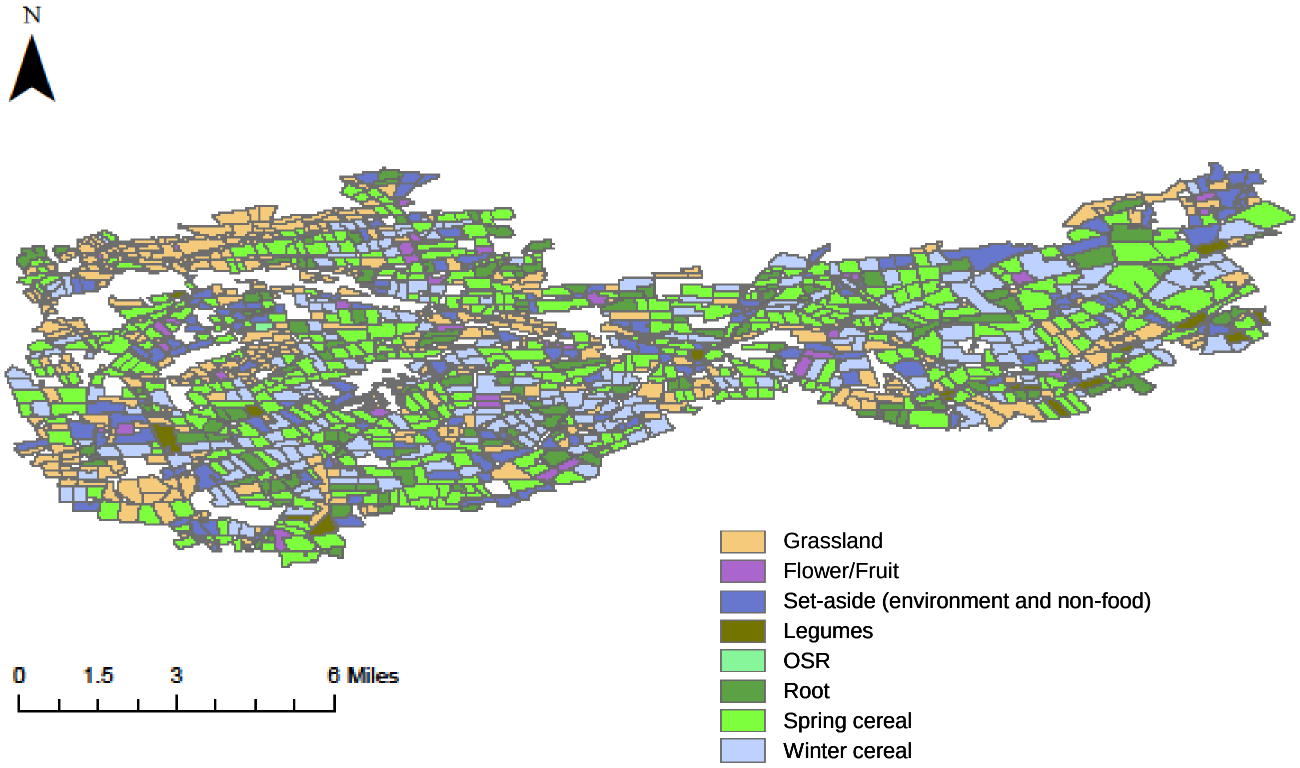

Figure H.3 - Spatial allocation of Land uses in the Lunan catchment in 2007 (IACS data)

Appendix I

GIS-Layers

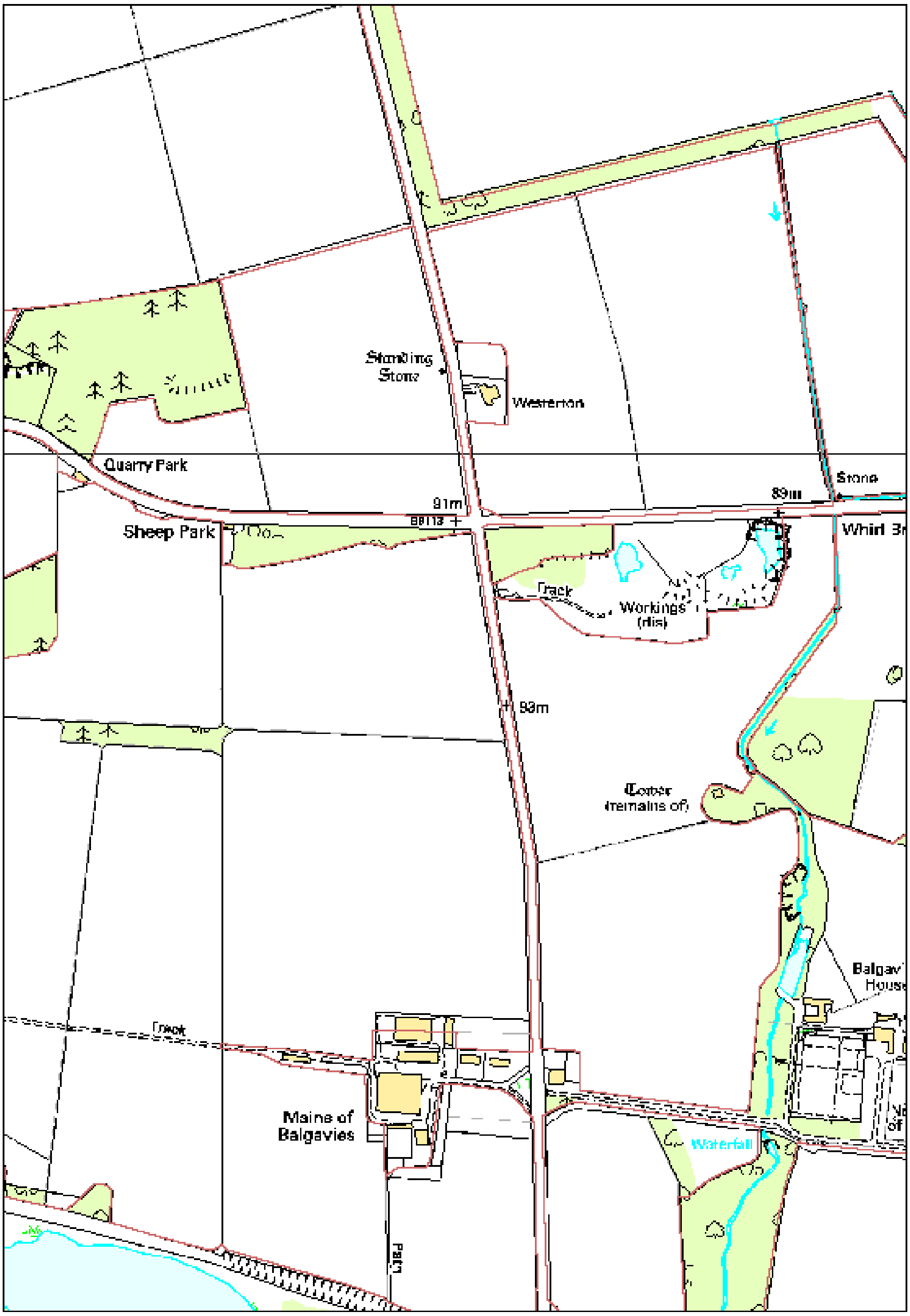

Figure I.3 – Vector Map of IACS Parcels (parcels are delimited by grey lines, farm boundaries are delimited by red lines) joined to Raster Map of the Lunan area (source: Digimap). The vectorisation of the digimap layer could improve the spatial definition of the catchment, e.g. field boundaries, distance to water, distance from field to farm

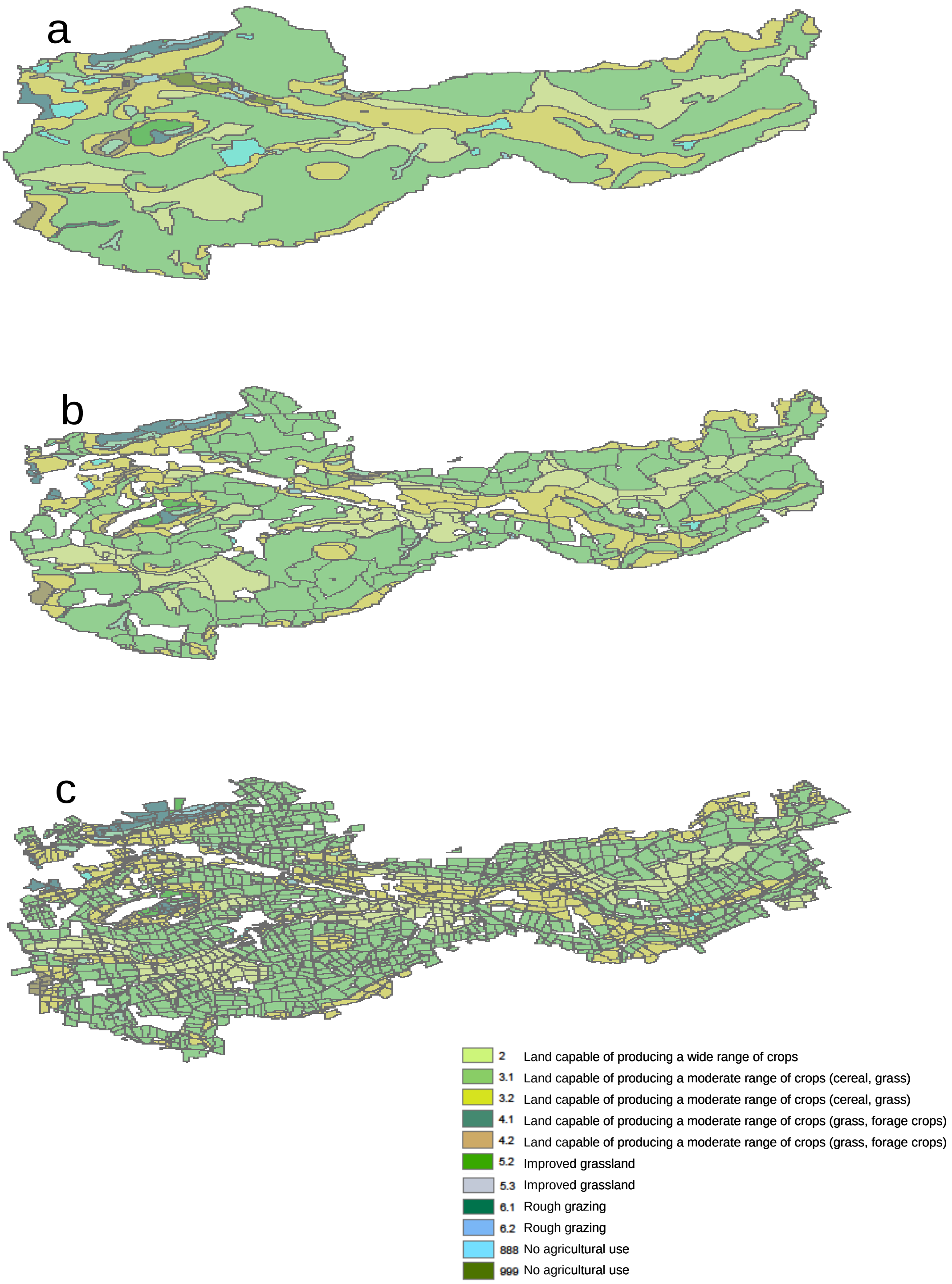

Figure I.2 - Union of Land Capability Map (a) to farm boundaries (b) and parcels (c). Source: Marie Castellazzi, James Hutton Institute. For more details on the legend see: http://www.macaulay.ac.uk/ruralsustainability/LFAreport.pdf

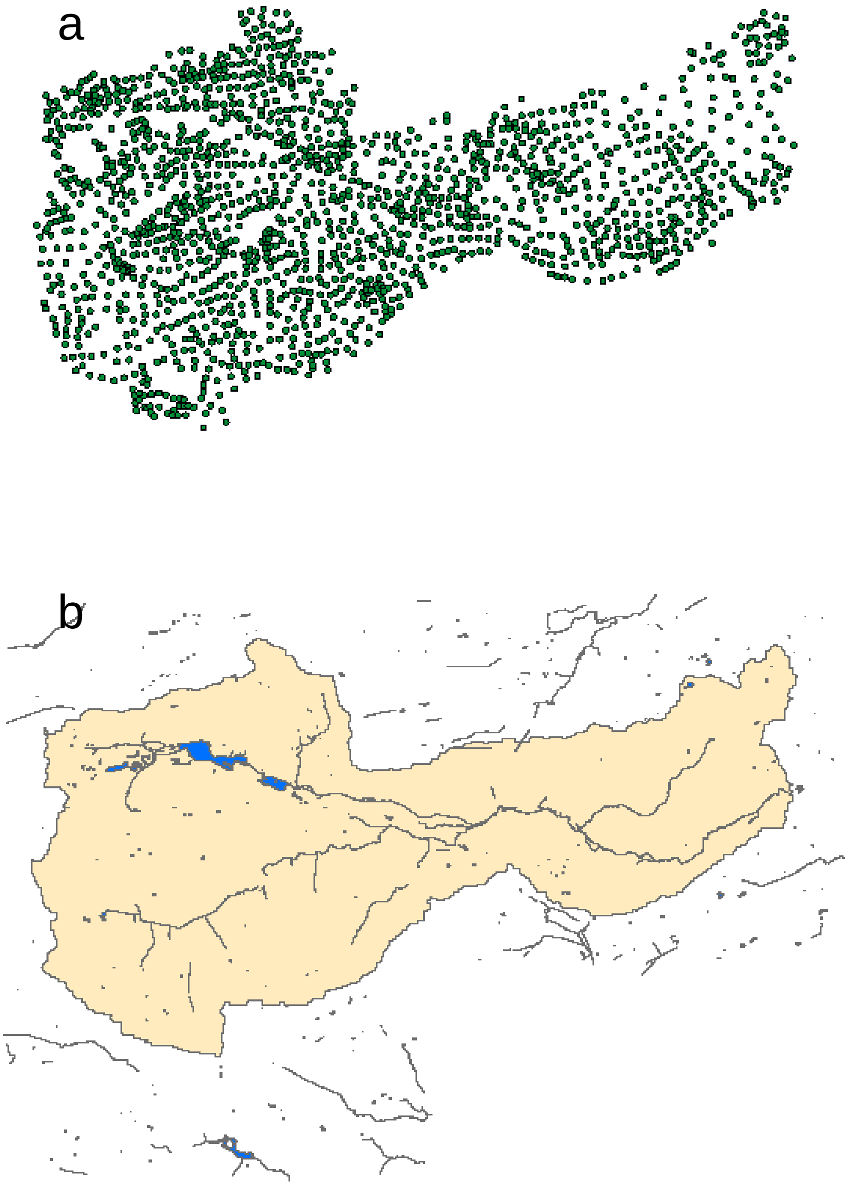

Figure I.3 - a) Spatial allocation of field of different sizes. The use of centroid permits to locate areas where parcels are small (agglomeration of points). b) Water bodies (source: Digimap)

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